Attempts to find a solution to the problem of atropisomer interconversion in 1,8-diarylnaphthalenes and 5,6-diarylacenaphthenes

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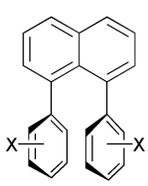
A series of sterically restricted 5,6-diarylacenaphthenes **5**, **11**, **12**, **13** and **14** have been prepared *via* Suzuki cross-couplings of the appropriate boronic acids with 5,6-dibromoacenaphthene **3** in an attempt to prevent atropisomer interconversion in these systems. Attempts to further functionalise bis(*p*-methoxyphenyl) system **5** in the position *ortho* to the methyl ethers by Friedel–Crafts acylation or metallation were unsuccessful; however, two unexpected products were obtained. *p*,*p*′-Dimethoxybiphenyl **6** results from an unexpected rearrangement of **5** under strongly basic conditions and is dependent on the base used, whilst acylated derivative **7** results from a Friedel–Crafts acylation of the acenaphthene scaffold in the 3-position, rather than the desired functionalisation of the *peri*-aryl rings, presumably due to the difficulty in forming a tetrahedral intermediate. The oxygen functionality in **5** has been used, following methyl ether cleavage *via* diphenol **8** and allylation *via* **9**, to demonstrate the viability of a double Claisen rearrangement yielding **11** after acetylation. However, the broad ^{1}H NMR exhibited by **11** clearly showed that this system is not configurationally stable, hence steps were required to access more sterically demanding systems which would be configurationally stable. Molecular mechanics and semi-empirical simulations were carried out on related biaryl systems to determine if a single bulky substituent in the 3-position of the *peri*-aryl rings would be sufficient to prevent atropisomer interconversion. The modelling showed that the energies of the *syn*- and *anti*-atropisomeric forms, *e.g.* for **12**–**14**, were surprisingly similar. With the objective of preparing conformationally stable molecules in this class in mind, **12**–**14** were prepared in remarkable yield for such a hindered system. In spite of extensive attempts to determine whether **13** was configurationally stable, enantiomeric separation could not be achieved. Unsuccessful attempts were thus made to detect the presence of stable atropisomeric forms of **13** through the synthesis of bis(benzyl ether) **19**, in which the benzylic protons could act as enantiotopic reporters. In addition mandelate ester **20** was prepared and it was shown by ^{1}H NMR that a mixture of *anti*- and *syn*-diastereoisomers had been obtained. It was therefore concluded that steric groups in the 3-position of the *peri*-aryl rings cannot be used to prevent atropisomer interconversion in 1,8-diarylnaphthalenes and 5,6-diarylacenaphthenes. During attempts to access diphenols **18** and **24**, other by-products were isolated, *i.e.* **21** and **25** respectively, resulting from a steric strain-induced 1,2-aryl shift.

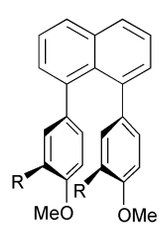
Introduction

1,8-Diarylnaphthalenes and their structural analogues 5,6-diarylacenaphthenes have presented a considerable challenge to organic chemists for a number of years.[1] House and co-workers reported the preparation of the first example of this series, *i.e.* 1,8-diphenylnaphthalene, in 1963.[1a] The interest in these systems lay in the steric encumbrance between the 1,8-diaryl rings which, when compared with related optically active systems, was believed to be sufficiently large to prevent interconversion between atropisomeric forms **1a**–**1b**, if suitably substituted derivatives could be prepared. Thus, if the C_2-symmetric, and potentially chiral, *anti*-form **1b** could be stabilised, a new class of chiral molecules would become available. Subsequent studies of representative species[1c–e] with *meta*-substituents on the *peri*-diaryl rings showed that there was a dynamic equilibrium at room temperature between *syn*- and *anti*-atropisomeric forms, with surprisingly low rotational energy barriers which were reported to be of the order of 16 kcal mol^{-1}.[1d,e] The important consequence of this low energy barrier to rotation, in all of the systems studied to date, is that C_2-symmetric systems such as **1b** are not conformationally stable at room temperature. Thus, they cannot be used in asymmetric synthesis and catalysis, in direct contrast to other conformationally stable C_2-symmetric atropisomers.[2]



1

a; X groups *syn*
b; X groups *anti*



2

R = CHO

A partial solution to this problem was reported by Clough and Roberts,[3] who showed that it was possible to isolate both *syn*- and *anti*-atropisomer forms when methyl groups were placed in the *ortho*-positions of the *peri*-aryl rings (**1**, X = 2-methyl). Unfortunately, the two atropisomers were only conformationally stable in the solid state; atropisomer interconversion occurred in solution despite a rotational energy barrier of 24.1 kcal mol^{-1}. A number of other workers have further

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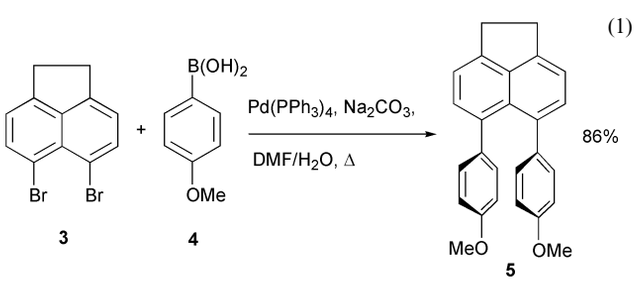
investigated the electronic effects of unsymmetrical diaryl ring substituents on the rotational energy barriers to interconversion between 1,8-diarylnaphthalene atropisomers without success in preventing atropisomer interconversion.[4]

Our interest in this area was initiated after employing a 1,8-diarylnaphthalene framework as a ligand spacer for constructing a bis-manganese binding ligand system.[5a] A subsequent crystal structure determination of one of the ligand precursors, *i.e.* **2**, demonstrated the exclusive isolation of the *syn*-atropisomer in the solid state.[5b] Due to difficulties associated with the preparation of dialdehyde **2**[5a] and because the preparation of conformationally stable *anti*-1,8-diarylnaphthalenes is of such great interest, a wider ranging study was undertaken with particular emphasis on attempting to find a solution to the problem of preventing aryl ring rotation and hence atropisomer interconversion. Herein, we present the full details on the synthesis of a number of hindered diarylnaphthalene derivatives and the problems associated with accessing such hindered systems.

Results and discussion

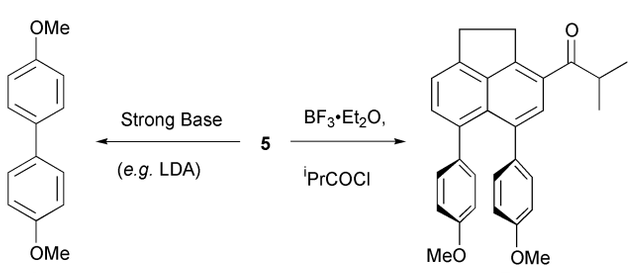
Functionalisation of 5,6-bis(4-methoxyphenyl)acenaphthene

Our original synthetic route to **2** involved the use of 1,8-diiodonaphthalene, which was prepared by the reported procedure.[1e] However, due to the capricious nature of this procedure and the instability of the resulting diiodide, we decided to rely upon the structurally related 5,6-dibromoacenaphthene **3**,[6] because this could be readily prepared in large quantities and stored indefinitely. Our efforts centred on the preparation of the *p*-methoxy system **5**, since this could be a useful synthon for the preparation of a range of *meta*-substituted 5,6-diarylacenaphthenes, prepared for example *via ortho*-metallation or Friedel–Crafts methodologies. Thus **3** was reacted with boronic acid **4** under Suzuki coupling conditions, producing diaryl system **5** in high yield [eqn. (1)].



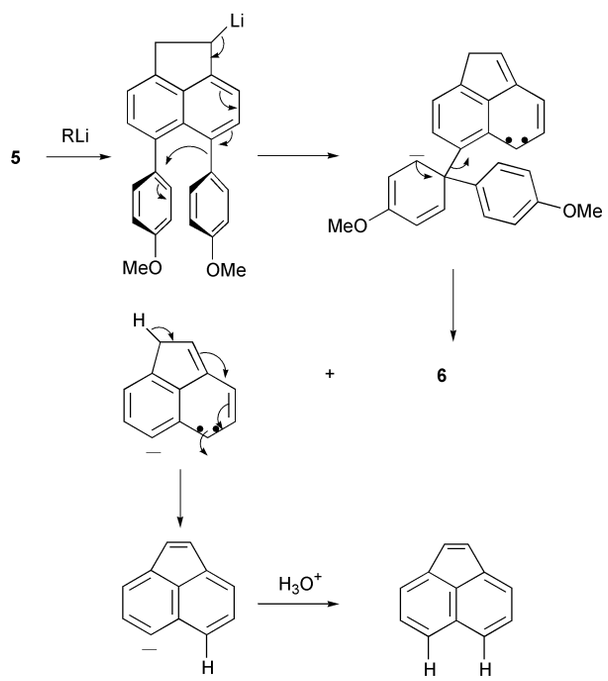
(1)

We then attempted to functionalise the *peri*-aryl rings using *o*-methoxy metallation conditions, however the use of strong bases such as LDA and *tert*-butyllithium, followed by the addition of various simple alkylating agents, was wholly unsuccessful (Scheme 1). In all cases, considerable quantities of



Scheme 1

unreacted starting material **5** were recovered and there was no evidence of reaction with electrophiles such as chlorotrimethylsilane. We were able to identify variable quantities of biaryl **6** as an unexpected by-product from the reaction, by comparison with an authentic sample.[7] The appearance of by-product **6** was dependent on both the temperature and the alkyllithium reagent used. Thus, when *tert*-butyllithium was employed (THF, −78 °C, 4 hours), no reaction was observed. However, when the same reaction was carried out at −40 °C, the crude reaction mixture showed a 2 : 1 mixture of compounds **5** : **6** (determined by ^{1}H NMR). When the base was changed to LDA in diethyl ether at room temperature, a more efficient conversion to biaryl **6** took place, producing a 1 : 1 ratio of **5** : **6** in the crude reaction mixture (again determined by ^{1}H NMR). When the analogous reaction was performed in diethyl ether at room temperature using *tert*-butyllithium, less than 4% of the biaryl **6** was generated. It is possible that these observations can be explained by the generation of a carbene anion from the 5,6-diarylacenaphthene system **5**, which could undergo subsequent rearrangement to **6**, as shown in Scheme 2. However, we have



Scheme 2

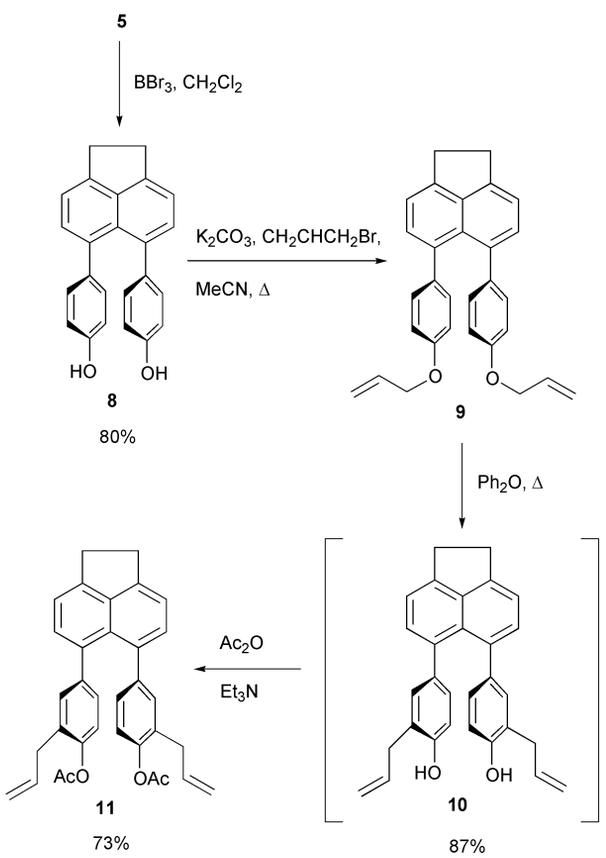
been unable to identify or isolate any by-products resulting from the acenaphthene system to reinforce this scheme.

Friedel–Crafts reactions were similarly unsuccessful at producing the required substitution *ortho* to the methoxy groups on the phenyl rings of diaryl **5**. Even under more drastic conditions, such as $AlCl_3$ or $TiCl_4$ at elevated temperatures with a large excess of the corresponding acid chlorides, no *o*-methoxy substitution products could be identified and starting material was generally recovered, although some decomposition also took place. The only exception to this seemed to be when excess $BF_3{\cdot}Et_2O$ and isobutyryl chloride were used; an acylated product was observed, but this could not be obtained in a pure state. The ^{1}H NMR spectrum of this impure product suggested the addition of one isobutyryl function to the acenaphthene ring, rather than the anisyl ring, due to the presence of two pairs of *p*-methoxyphenyl rings, two hydrogen, 8.8 Hz doublets. In addition, EI mass spectrometric analysis did reveal a molecular ion corresponding to the correct constitution for structure **7** (*m*/*z* 436.2038 M^+, $C_{30}H_{28}O_3$ requires 436.2038).

One can speculate that this acylated product could have structure **7** (Scheme 1), however, the most important finding was obviously that the phenyl rings were seemingly completely unreactive towards this type of electrophilic aromatic substitution reaction. This lack of Friedel–Crafts reactivity on the *peri*-aryl rings presumably results from the extreme steric

restrictions enforced by the proximity of the two phenyl rings. Such repulsion is presumably sufficient to prevent the formation of the necessary tetrahedral carbonium ion intermediate.

In view of the lack of reactivity in these diaryl systems an entirely different methodology had to be adopted to incorporate chemical functionality in the positions *ortho* to the methoxy groups in diaryl **5**. One possibility could be to use the oxygen substituents of **5** to deliver a functional group in a regio- and potentially stereo-selective manner using a Claisen rearrangement, *i.e. via* bis(allyl ether) **9**. Thus, if the 5,6-diarylacenaphthene system was sufficiently conformationally stable, the two allyloxy functions might reasonably be expected to rearrange in opposite directions, to produce an *anti*-configuration of the allyl functions in the product **10**. We therefore decided to investigate the viability of performing such a double Claisen rearrangement, starting with cleavage of the methyl ethers of dimethoxy system **5**, followed by Williamson ether formation to provide bis(allyl ether) **9** (Scheme 3).

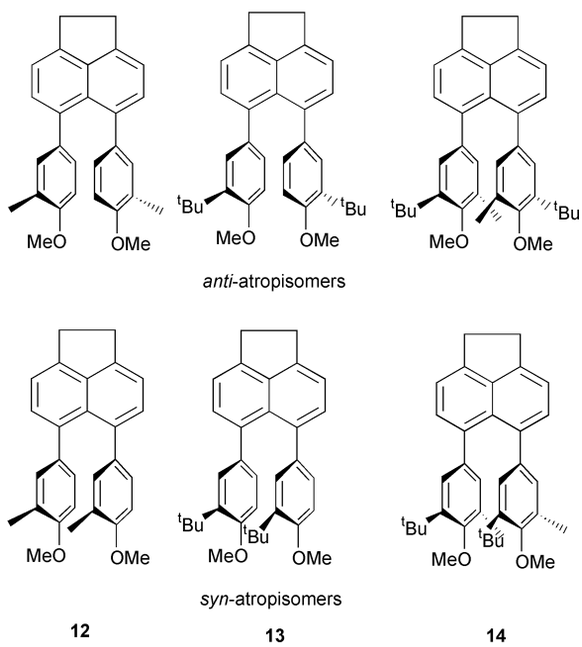


Scheme 3

Having accessed diether **9**, the Claisen rearrangement was then investigated, but proved to be more difficult than expected. No reaction of diether **9** occurred in refluxing DMF or diethylaniline, even when it was heated at 210 °C in a sealed tube for 3 days. However, rearrangement could be forced by refluxing in diphenyl ether,[8] which produced a rapid (*ca.* 30 minutes) and clean rearrangement to produce diphenol **10** in quantitative crude yield. The relatively extreme conditions required to trigger the Claisen rearrangement again reinforce the severe constraints which operate on such systems. Clearly, for rearrangement of **9** to take place, a tetrahedral intermediate has to be formed; however, formation of such an intermediate is severely compromised by increasing steric repulsion as the transition state forms. Hence, elevated temperatures are required to accomplish the reaction. Due to the sensitivity of this resulting diol **10**, immediate *in situ* acetylation was carried out, to give the corresponding diacetate **11** in good yield (Scheme 3). Having isolated the stable diacetate **11**, it was immediately obvious from the nature of the broad ^{1}H NMR spectrum, that it was not possible to determine whether allyl migration had occurred in an *anti*-sense. The NMR spectrum clearly demonstrated that there was some restricted rotation occurring around the biaryl bonds, *i.e.* at room temperature, the ^{1}H NMR spectrum of **11** was remarkably different to that previously reported for aldehyde **2**.[5] Signal broadening indicated that atropisomer interconversion was occurring; a first order spectrum was observed, however, on heating to 388 K in $CDCl_3$. In view of the lack of configurational stability of the diaryl system **11**, it was decided that a systematic investigation was required to identify the contributing factors which determine configurational stability in such diarylnaphthalene systems.

Molecular modelling of diphenylnaphthalene systems

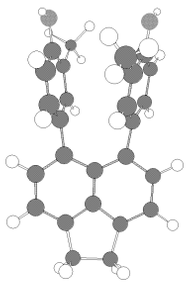
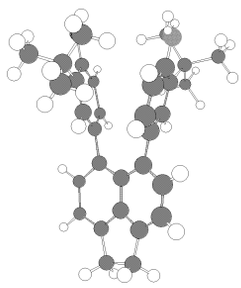
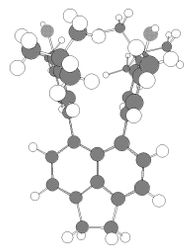
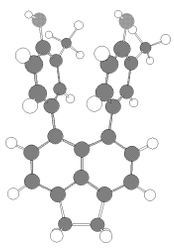
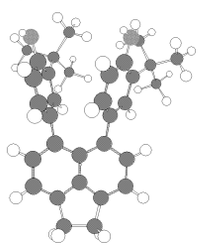
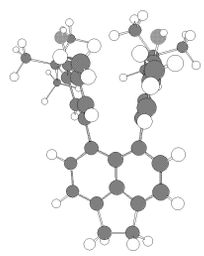
Preliminary molecular mechanics-based simulations[9] and semi-empirical (AM1)[10] calculations were therefore carried out to study the rotation process in a series of closely related 1,8-diarylnaphthalene systems and their corresponding 5,6-diarylacenaphthene systems (**12**–**14**), which can exist in their

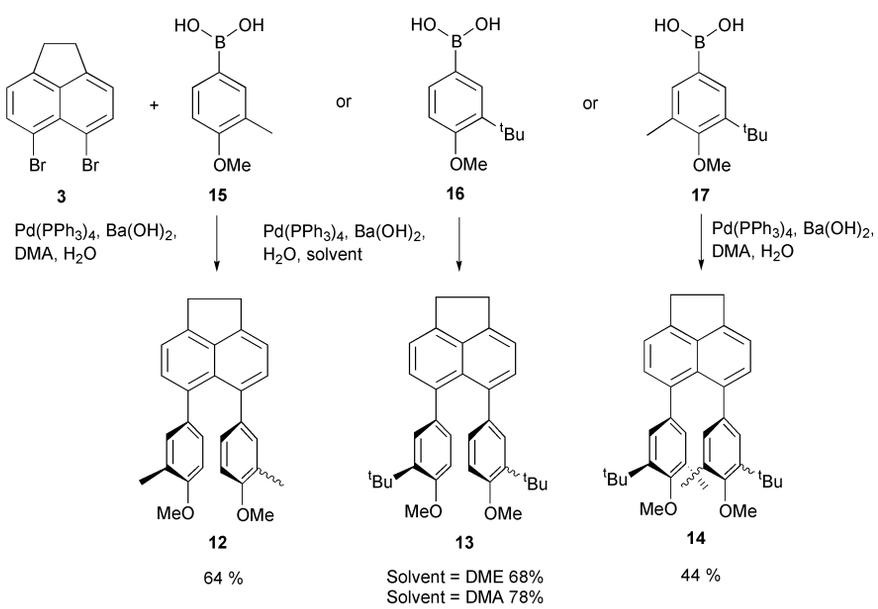


syn- and *anti*-forms. Close agreement was found between these two modelling methods when locating the lowest energy structures in each of the cases **12**–**14**, for both the *syn*- and *anti*-configurations of both 1,8-diarylnaphthalenes and 5,6-diarylacenaphthenes; the results are summarised in Table 1 for the acenaphthene series.

Examination of the models of structure **12** (Table 1, Entry 1) demonstrates that the acenaphthene–phenyl bond is capable of some degree of bending. In addition, the naphthalene unit can twist to reduce steric repulsion between phenyl rings. The net result of these two deformations may be to allow aryl ring rotation, *i.e.* when the deformations become sufficiently large, atropisomer interconversion between the *syn*- and *anti*-forms of **12** will occur. This analysis therefore points to a possible solution of the problem of interconversion. There is a need to overcome the flexibility associated with both of the biaryl C–C bonds and the naphthalene or acenaphthene ring system. If the steric barriers could be made sufficiently large, one might be able to prevent atropisomer interconversion. Therefore, atropisomer stabilisation could hinge on finding suitable phenyl ring substituents which would force the phenyl rings apart to the maximal extent and yet still prevent phenyl ring rotation. We postulated that a *tert*-butyl group in the 3-position of the phenyl rings, *i.e.* **13**, might be sufficiently bulky to prevent

Table 1 MM2 calculated for three different diarylacenaphthenes

Entry	1	2	3
anti			
Energy difference (*anti* − *syn*)/kJ mol^{-1}	1.65	5.48	4.18
syn			



Scheme 4

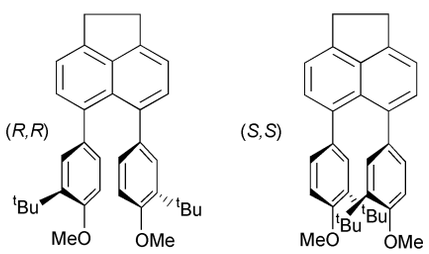
atropisomer interconversion, without the need for a further substituent in the 5-position. However, if it was possible to access a 3,5-disubstituted system such as **14**, it would be even more likely that stabilisation of the system would result. In addition to this analysis, the modelling summarised in Table 1 produced some surprising and interesting information. Table 1 shows the relative energies of the *anti*- *versus syn*-atropisomers for the acenaphthene-derived structures **12**–**14**, which were virtually identical to those obtained for the identically substituted naphthalene systems, clearly showing that the bridging ethylene unit has virtually no effect upon atropisomer stability. Even more important however, was the finding that the energies for the *anti*- and *syn*-atropisomers are very similar indeed, *i.e.* within 5.48 kJ mol^{-1} of each other. Therefore, there is not the latent instability of the *syn*-atropisomers that one might intuitively expect. Clearly, since the energy differences between the *syn*- and *anti*-atropisomers are small, facile atropisomer interconversion will occur if the barriers to rotation are not made sufficiently large. The *tert*-butyl system **13** has the largest energy difference between *syn*- and *anti*-atropisomers and this could be sufficient to ensure that the *anti*-form predominates during attempts to prepare such systems. However, the question remained as to whether the rotation barrier would be sufficiently large to prevent subsequent thermal equilibration to a mixture of *syn*- and *anti*-forms. Adding a further steric barrier to derivative **14** did not substantially increase the energy difference between atropisomers, hence a structure such as di-*tert*-butyl system **13** appeared to be the best synthetic candidate in order to attempt separation of the atropisomeric forms. This task was undertaken, together with the preparation of analogues of **12** and **14** to act as comparisons to **13**.

Synthesis and attempted functionalisation of substituted 5,6-diphenylacenaphthenes

Boronic acids **15**–**17** were prepared from the corresponding 4-bromoanisoles[11] and coupled with 5,6-dibromoacenaphthene **3** under Suzuki conditions, as implemented by Snieckus[12] (Scheme 4) together with exhaustive deoxygenation (using a freeze–pump–thaw routine prior to reaction) to produce diaryls

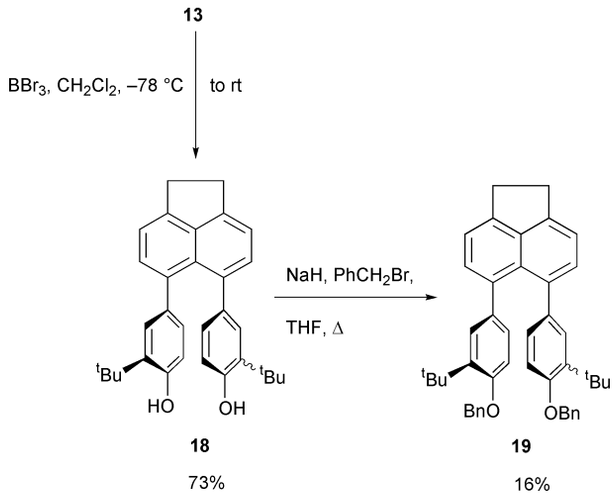
12–**14** in exceptional yields, considering the steric hindrance in such systems. As anticipated, the ^{1}H NMR spectrum of **13** at 200 or 300 MHz appeared to be simple and sharp, suggesting that either a major diastereoisomer had been obtained, or that rapid rotation was occurring between atropisomeric forms. The same observation applied to the more hindered system **14**; however, the less hindered system **12** was again broad by 300 MHz ^{1}H NMR, as had been found for diallyl system **11**.

Low temperature ^{1}H NMR experiments were therefore carried out on di-*tert*-butyl system **13**; no apparent changes in the line shape (*i.e.* broadening or sharpening) were observed upon cooling to 240 K in $CDCl_3$ at 200 MHz. Similarly, heating in benzene to 345 K produced no obvious changes to the spectrum. This finding, taken in comparison with the ^{1}H NMR behaviour of **11**, **12** and **14**, seemed to suggest that the di-*tert*-butyl system **13** might have been exclusively isolated as a single atropisomeric compound (presumably *anti*), directly from the Suzuki coupling reaction. Structures **11** and **12** were obviously an interconverting mixture of *syn*- and *anti*-atropisomers on the NMR timescale, with the hindered system **14** behaving similarly to **13**. This may appear to be contradictory to the molecular modelling results, *i.e.* that there was very little difference in energy between the *syn*- and *anti*-atropisomeric forms of all three structures examined. However, the gas phase calculations did not take into account the steric constraints that are likely to be encountered during the Suzuki cross-coupling reactions,[13] nor were the barriers to interconversion estimated. Reinforcement of this analysis appeared to come from single crystal X-ray diffraction studies on **13**, which revealed that only the



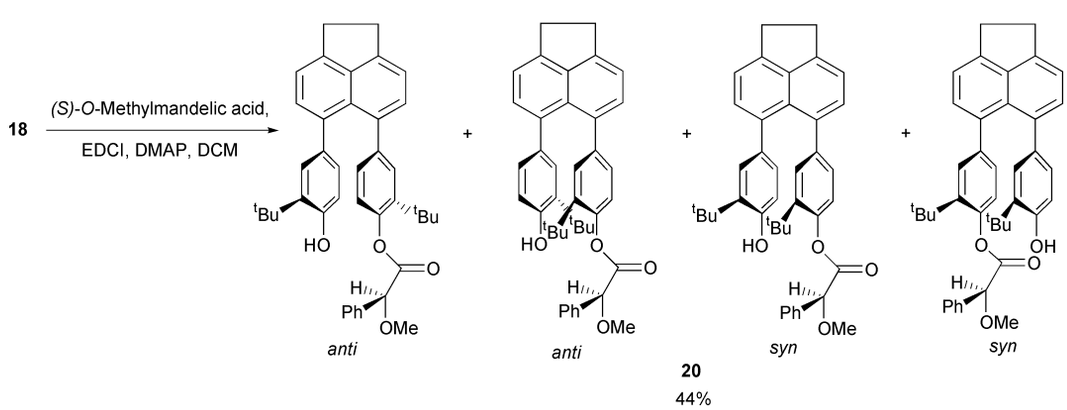
anti-atropisomer was present in the crystal lattice,[14] the structure of which was almost identical to that predicted by molecular modelling.[9,10] The suggestion of conformational stability of **13** in the *anti*- (chiral) form, *i.e.* a racemic mixture of **13a** and **b**, meant that it might be possible to demonstrate that *anti*-**13** was stable and chiral by the presence of a racemic mixture of the enantiomers, for example by chiral HPLC. However, exposure of **13** to a wide range of chiral HPLC columns produced absolutely no evidence of separation. However, this did not necessarily prove that **13** was undergoing aryl ring rotation and therefore atropisomer interconversion, rather that we were unable to find a suitable separation system.

Alternative methods were therefore required to probe this matter further, *i.e.* whether it was indeed possible to differentiate or separate enantiomers **13a** and **b**. Replacement of the methyl ethers of **13** with benzyl ethers to give **19** might betray the presence of asymmetry; the benzylic protons would be expected to appear as an AB quartet rather than a singlet, helping to confirm their possible diastereotopic nature. Thus, cleavage of the methyl ethers of **13** proceeded reasonably smoothly, yielding diol **18**, which was immediately converted to the bis(benzyl ether) **19** (Scheme 5). Unfortunately, the benzylic protons of **19** appeared as a singlet at room temperature, perhaps suggesting that atropisomer interconversion was occurring.



Scheme 5

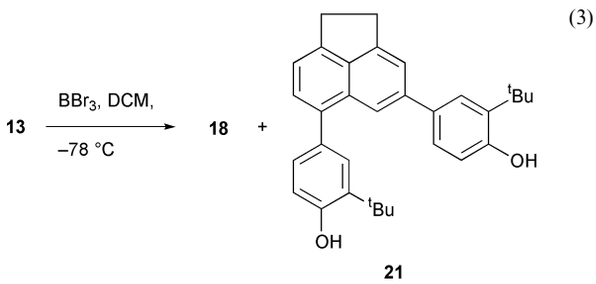
An alternative approach to probing the rotational stability of the bis(*tert*-butylphenyl) systems **13** and **18** would be the conversion of **18** to a mixture of diastereoisomers by coupling with a homochiral auxiliary, which could be separated by chromatographic or fractional crystallisation techniques. Therefore, conversion to the mono-*O*-methylmandelate ester **20** was carried out initially using a conventional DCC coupling method.[15a] Although the mono-ester **20** could be readily prepared by this method [eqn. (2)], separation from the urea by-products proved difficult. This was additionally complicated by the extreme sensitivity of the mono-ester **20** to hydrolysis, a process which is presumably auto-catalytic as a result of the remaining *peri*-phenol function in **20**. It was however possible to isolate a pure sample of **20** using a water soluble DCC equivalent, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDCI·HCl),[15b] in the presence of a stoichiometric quantity of DMAP. The 400 MHz ^{1}H NMR spectrum of mandelate ester **20** showed that it was a mixture of diastereoisomers, corresponding to the (*S*)-*O*-methylmandelates formed from the (*R*,*R*), (*S*,*S*), (*R*,*S*) and (*S*,*R*)-atropisomers [see eqn. (2)]. It was not possible to separate the diastereoisomers of **20** using a variety of chromatographic and separation methods, without decomposition taking place, presumably due to the *peri*-hydroxy function catalysing ester hydrolysis. These results



(2)

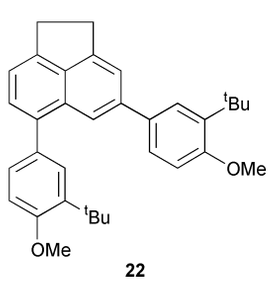
suggest that the isolation of three diastereoisomers of **20** results from the added rotational stabilisation provided by the presence of the mandelate ester function, which acts to slow aryl ring rotation, rather than the latent stability of its atropisomeric precursor diol **18**, or the corresponding bis(methyl ether) **13**. Added stability of the diastereoisomers of **20** may also result from phenol–mandelate ester hydrogen bonding, which in turn adds to the esters' sensitivity to hydrolysis.

Further clarification of our understanding of system **18** and its precursor **13** was obtained when a larger scale cleavage of bis(methyl ether) **13** was attempted [eqn. (3)]. In addition to

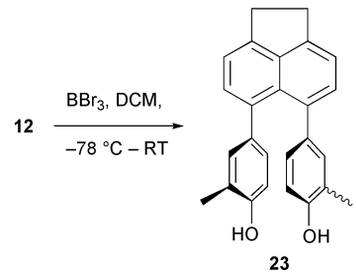


(3)

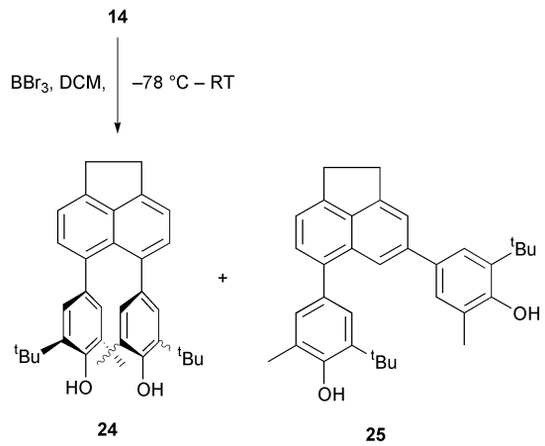
the major product, diphenol **18**, another minor product was formed, which could be isolated individually by careful silica gel chromatography. It was immediately apparent that this new compound was dramatically different to the C_2-symmetric precursor **13** and the diphenol **18** by both ^{1}H and ^{13}C NMR. In addition, mass spectrometry verified the fact that this new compound had also resulted from bis(methyl ether) cleavage of **13**, since it had the same mass and empirical formula as diol **18**, but it had lost its C_2-symmetry (^{1}H NMR). Our initial rationalisation of this product was that the product could be the *syn*-atropisomer of **18**, perhaps resulting from a retro-Friedel–Crafts (retro-*tert*-butylation), re-Friedel–Crafts reaction on the *anti*-bis(methyl ether) **13** (assuming *anti*-**13** was configurationally stable), perhaps caused by hydrogen bromide contamination in the poor quality boron tribromide solution. After bis(methyl ether) cleavage, *syn*-**18** could therefore have been isolated. Subsequent studies of the bis(methyl ether) **13** with boron trichloride showed that a 1,2-aryl shift could take place to provide corresponding rearranged structure **22**, without con-



comitant methyl ether cleavage. Single crystal X-ray diffraction confirmed the integrity of **22**, which has been reported elsewhere,[16] and comparison of the ^{1}H and ^{13}C NMR spectra of the new product from eqn. (3) with those of **21** revealed that a 1,2-aryl shift and demethylation had resulted in the isolation of diol **21**, rather than *syn*-**18**. Such aryl ring shifts are not well documented and seemingly result from the severe steric strain inherent in the bis(*tert*-butylphenyl) system **13** in this case. Further light was shed upon this reaction and the effect of strain upon the reaction outcome by the following reactions and observations: a) treatment of the less hindered bis(methyl ether) **12** with boron tribromide failed to provide any evidence of rearrangement [eqn. (4)], simply producing unrearranged diol **23**; b) treatment of hindered system **14** with boron tribromide similarly produces diphenol **24** and the rearranged compound



(4)



(5)

25 [eqn. (5)]; c) diphenol **18** is resistant to rearrangement by treatment with boron tribromide. These observations, taken together with the fact that trace amounts of rearranged product **21** were always present in the crude reaction mixture from the methyl ether cleavage of **13**, strongly suggest that the reaction is a) triggered by the additional strain inherent in systems **13** and **14**, *versus* **5** or **12**; and b) occurs only on the methyl ethers **13** and **14**, *i.e.* does not occur once demethylation has occurred, under these relatively mild reaction conditions. A likely mechanism which may explain the observed outcome has been discussed in detail elsewhere.[16]

Summary

The synthesis of a series of substituted 5,6-bis(*p*-methoxyphenyl)acenaphthenes has been developed using Suzuki coupling methods. All the systems prepared exhibit both physical and chemical properties which reflect the severe phenyl–phenyl ring repulsions, clearly exemplified by: a) resistance to Friedel–Crafts acylation, presumably due to steric inhibition of the transition that would result from electrophilic attack upon one of the phenyl rings, and b) the occurrence of strain-induced 1,2-aryl shifts with apparent ease, which relieves phenyl–phenyl ring repulsion. However, despite the severe steric strain between the 5,6-phenyl rings in the acenaphthene series reported herein, it was not possible to harness this strain to prevent atropisomer interconversion in any systems purely by substitution in the positions *ortho* to the methoxy groups. However, such studies will prove important in order to gain a structure *versus* dynamics[14] understanding, which is reported elsewhere. It is clear that in order to be able to design new, atropisomerically stable chiral ligands based upon 5,6-acenaphthene or 1,8-naphthalene frameworks it will be necessary to functionalise the phenyl ring systems in other positions; such studies are well underway and the results will be published in due course.

Experimental

THF was freshly distilled under argon from benzophenone ketyl. Dichloromethane was freshly distilled under argon from calcium hydride. 5,6-Dibromoacenaphthene[6] and 2-*tert*-butyl-

4-bromophenol[11] were prepared as reported in the literature. $Pd(PPh_3)_4$ was prepared as reported in the literature[17] and sealed under argon in glass ampoules prior to use.[18] All other reagents were purchased from Aldrich or Lancaster and were used without further purification. Column chromatography was performed under medium pressure on silica gel (Acros, pore size 60 Å) and neutral alumina G_{254} (Merck). All anhydrous, low temperature reactions were carried out in glassware, which was dried prior to use in an oven at 140 °C and cooled under a stream of argon. All evaporations were carried out by partial evaporation on a rotary evaporator, followed by solvent drying *in vacuo* at approximately 0.5 mmHg. All Suzuki coupling reactions were performed under strictly anaerobic conditions with all solvents being thoroughly degassed prior to use by a freeze (liquid nitrogen), pump (high vacuum, *ca.* 0.5 mmHg), thaw process (three cycles). All melting points are uncorrected and were measured on a capillary melting point apparatus. Room temperature ^{1}H NMR spectra were recorded at 200, 300 or 400 MHz on Bruker AC200, AC300 or DPX400 spectrometers respectively, using residual incompletely deuterated solvent as the internal standard. Coupling constants are given in Hz. Variable temperature ^{1}H NMR were measured on a Bruker AC300 spectrometer at 300 MHz. ^{13}C NMR were recorded at 75.5 or 100 MHz on Bruker AC300 and DPX400 instruments respectively. Low resolution fast atom bombardment (FAB) mass spectra were recorded on a Kratos MS50 mass spectrometer using an *m*-nitrobenzyl alcohol matrix. High resolution electron impact (EI) mass spectra were recorded on a Kratos Concept IS spectrometer. Infrared spectra were recorded on a Perkin-Elmer 298 spectrometer for thin films on KBr plates or KBr discs. UV–Vis spectra were recorded on a Perkin-Elmer 115 spectrometer. Microanalyses were performed using a Carlo-Erba 1106 elemental analyser. Chiral HPLC was undertaken by the use of either a Chiralpak AD, OD or Chiracel OF chiral column with a Pye Unicam UV detector and pump.

4-Bromo-2-*tert*-butylanisole

4-Bromo-2-*tert*-butylphenol[11] (8.43 g, 0.037 mol) was placed in a dry round bottomed flask. THF (150 cm^3) and methyl iodide (15.28 g, 0.11 mol) were added under an argon atmosphere, followed by the cautious addition of sodium hydride (2.15 g, 0.054 mol). Once foaming had ceased the resultant mixture was heated under reflux for 12 h, after which it was cooled and then quenched cautiously with dilute hydrochloric acid (10 cm^3). The resultant mixture was concentrated *in vacuo* and partitioned between diethyl ether (200 cm^3) and dilute hydrochloric acid (100 cm^3). The organic phase was collected, washed with brine (50 cm^3), dried with $MgSO_4$ and evaporated to yield a light brown oil. This material was purified by distillation to yield 4-bromo-2-*tert*-butylanisole (8.90 g, 100%). All data are consistent with those reported in the literature;[19] δ_C (75.5 MHz; $CDCl_3$) 29.6 [C(CH_3)$_3$], 35.2 [C(CH$_3$)$_3$], 55.4 (OCH_3), 133.1, 140.8 and 157.8 (Ar-*C*), 113.3, 129.7 and 129.8 (Ar-*C*H).

4-Bromo-2-*tert*-butyl-6-methylphenol

This was prepared by an analogous procedure to that reported in the literature for the preparation of 4-bromo-2-*tert*-butylphenol[11] using 2-*tert*-butyl-6-methylphenol (10.0 g, 0.0608 mol) and tetrabutylammonium tribromide (35.2 g, 0.0720 mol) in $CHCl_3$ (150 ml) to yield 4-bromo-2-*tert*-butyl-6-methylphenol (14.8 g, 91%), mp 49–50 °C (Found: C, 54.5; H, 6.3; Br, 32.4. $C_{11}H_{15}BrO$ requires C, 54.3; H, 6.2; Br, 32.8%); ν_{max}/cm^{-1} 3580–3260b (OH), 3000–2860 (CH_3), 1600 and 1480 (aromatic) and 1150 (C–O); δ_H (300 MHz; $CDCl_3$) 1.41 [9 H, s, C(CH_3)$_3$], 2.24 (3 H, s, CH_3), 4.77 (1 H, s, O*H*), 7.15 and 7.26 (each 1 H, d, *J* 2.3, Ar-*H*) (addition of D_2O causes the peak at δ 4.77 to disappear); δ_C (75.5 MHz; $CDCl_3$) 16.2 (CH_3), 29.9 [C(CH_3)$_3$], 35.1 [C(CH$_3$)$_3$], 112.7, 125.6, 138.3 and 152.2 (Ar-*C*), 128.4 and 131.2 (Ar-*C*H); *m*/*z* (FAB) 242/244 (M^+; 100) and 227/229 ($M^+ - O$; 30%); *m*/*z* (EI) 242.0303 (M^+; $C_{11}H_{15}BrO$ requires 242.0307).

4-Bromo-2-*tert*-butyl-6-methylanisole

To a solution of 4-bromo-2-*tert*-butyl-6-methylphenol (4.0 g, 0.0163 mol) in anhydrous THF (100 cm^3) was slowly added sodium hydride (0.8159 g, 0.025 mol) under an inert atmosphere. The reaction mixture was allowed to stir at room temperature for 30 minutes prior to the dropwise addition of methyl iodide (5.81 g, 0.409 mol) with stirring. The reaction mixture was then heated to reflux for 3 h, cooled and then quenched with dilute hydrochloric acid. The reaction mixture was evaporated to dryness then extracted with diethyl ether, washed with dilute hydrochloric acid then saturated brine before drying over anhydrous $MgSO_4$. Concentration *in vacuo* followed by recrystallisation (40 : 60 petroleum ether) yielded (4.05 g, 96%) 4-bromo-2-*tert*-butyl-6-methylanisole as a colourless liquid, which was identical to that reported in the literature.[20]

Boronic acids 4 and 15, 16 and 17—general procedure

All boronic acids were prepared using methods reported in the literature[21] and were used without further purification. Compounds **4**, **15** and **16** were prepared in an identical manner *via* Grignard methodology, whereas **17** was prepared *via* lithium–halogen exchange. Representative procedures are as follows.

Representative procedure for 4 (or 15 and 16). A dry round bottomed flask was charged with magnesium turnings (0.979 g, 0.04 mol), a crystal of iodine and dry THF (100 cm^3). A few drops of a solution of 4-bromoanisole (6.85 g, 0.037 mol) in THF (50 cm^3) were added and the mixture heated until the reaction initiated. Once initiation had occurred, the reaction was maintained at reflux by the addition of the solution of 4-bromoanisole. Once addition was complete, the resulting grey solution was heated under reflux for a further two hours, prior to cooling to −78 °C. The Grignard reagent was then treated with trimethyl borate (8.32 cm^3, 0.07 mol) (dropwise addition) and the mixture was allowed to warm to room temperature overnight. The reaction was quenched with dilute hydrochloric acid (10 cm^3), and the mixture was evaporated and partitioned between equal volumes of diethyl ether and dilute hydrochloric acid (150 cm^3). The organic phase was dried ($MgSO_4$) and evaporated to yield a lightly coloured oil which was readily crystallised from diethyl ether–*n*-hexane to yield the boronic acid **4**[22] (4.37 g, 78%) as a white powder. [Other yields: **15**[23] (3.58 g, 87%), **16** (5.80 g, 76%). These boronic acids were used directly without any further purification in the cross-coupling reaction.]

Representative procedure for 17. A solution of 4-bromo-2-*tert*-butyl-6-methylanisole (5.0 g, 19.5 mmol) (dried under vacuum over P_2O_5), in dry THF (75 cm^3) under argon, was cooled to −78 °C and treated with *n*-butyllithium (11.5 ml, 2 M solution in hexane) (slow addition). After 1 h, trimethyl borate (2.38 g, 23.1 mmol) was added and the solution left overnight. The mixture was quenched with dilute hydrochloric acid (1 cm^3), diluted with ethyl acetate (75 cm^3), washed with dilute hydrochloric acid (3 × 10 cm^3) and saturated sodium chloride (75 cm^3). Separation and evaporation of the organic layer gave crude compound **17** (3.46 g, 81%) as a white solid. This product was used directly without any further purification in the cross-coupling reaction.

5,6-Bis(4-methoxyphenyl)acenaphthene 5

A round bottomed flask was charged with boronic acid **4** (0.1368 g, 0.90 mmol), 5,6-dibromoacenaphthene **3** (0.0936 g,

0.3 mmol), Na_2CO_3 (0.1272 g, 1.2 mmol), DMF (7 cm^3) and H_2O (3 cm^3). The mixture was thoroughly degassed before the addition of $Pd(PPh_3)_4$ (0.083 g, 7.2×10^{-5} mol) under argon. The resulting mixture was heated to 80 °C for 24 h before quenching with dilute hydrochloric acid (5 cm^3). The mixture was extracted with dichloromethane (2×25 cm^3) and the organic phase washed with dilute hydrochloric acid (4×25 cm^3), dried ($MgSO_4$) and evaporated to provide a crude oil. Purification by silica gel column chromatography (dichloromethane–hexane, 1 : 1 as an eluent) gave **5** (0.094 g, 86%) as a colourless crystalline solid, mp 176 °C (Found: C, 85.1; H, 6.1. $C_{26}H_{22}O_2$ requires C, 85.3; H, 6.1%); λ_{max}(Et_2O)/nm 310.8 (ε/dm^3 mol^{-1} cm^{-1} 11 374), 235.0 (43 909) and 215.6 (38 724); ν_{max}/cm^{-1} 3040 (aromatic H), 2920 (CH_2), 2840 (O–CH_3), 1610 and 1515 (aromatic), 1350 (C–O–CH_3) and 825 (*para*-substituted benzene ring); δ_H (300 MHz; $CDCl_3$) 3.49 (4 H, s, $2 \times CH_2$), 3.73 (6 H, s, $2 \times OCH_3$), 6.48 and 6.83 (each 4 H, d, *J* 8.8, $4 \times$ Ar-*H*) and 7.73 (4 H, s, $4 \times$ Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 30.2 (CH_2), 55.2 (CH_3), 112.6, 118.9, 130.7 and 131.3 (Ar-*C*H), 127.9, 134.9, 136.0, 140.5, 145.6 and 157.6 (Ar-*C*); *m*/*z* (FAB) 366 (M^+, 100%); *m*/*z* (EI) 366.1625 (M^+, $C_{26}H_{22}O_2$ requires 366.1620).

Attempts to functionalise bis(methoxyphenyl) 5 *via* metallation—general procedure

Bis(methyl ether) **5** (10 mg, 0.027 mmol) was dissolved in the appropriate dry solvent (THF or diethyl ether) under argon (at −78 °C, −40 °C or room temperature) and the alkyllithium or LDA (10 molar equivalents) added dropwise. The resultant orange solutions were allowed to stir at the desired temperature for 4 h, then the reactions were quenched with glacial acetic acid (10 molar equivalents). The solvent was evaporated, dichloromethane (10 cm^3) added and the organic phase washed with brine (10 cm^3). The organic phase was dried with $MgSO_4$, concentrated *in vacuo* and analysed by ^1H NMR which showed only unreacted starting material and biaryl **6** (which was identical to that reported in the literature[7]) in the following ratios: 1) *tert*-BuLi, −78 °C, THF, 100 : 0; 2) *tert*-BuLi, −40 °C, THF, 67 : 33; 3) *tert*-BuLi, 20 °C, Et_2O, 94 : 4; and 4) LDA, 20 °C, Et_2O, 50 : 50.

5,6-Bis(4-hydroxyphenyl)acenaphthene 8

A solution of bis(methyl ether) **5** (0.366 g, 1 mmol) under argon in dry dichloromethane (35 cm^3) was cooled to −78 °C and treated with boron tribromide (2.20 cm^3, 1 M solution in dichloromethane). The resulting black solution was warmed to room temperature. After 4 h, the reaction mixture was quenched with dilute hydrochloric acid (5 cm^3), diluted with ethyl acetate (50 cm^3), washed with dilute hydrochloric acid (50 cm^3) and dried ($MgSO_4$). After evaporation, the resulting oil was re-suspended in toluene (15 cm^3) and heated under reflux. Ethanol (*ca.* 2 cm^3) was added until a clear solution resulted. This clear solution was then allowed to cool to room temperature and evaporated until crystallisation began. Cooling to approximately −40 °C resulted in the formation of light brown crystals, which were collected by filtration, washed with *n*-hexane and dried *in vacuo* to yield diphenol **8** (0.270 g, 80%), mp 258 °C (decomp.) (Found: C, 85.4; H, 5.6. $C_{24}H_{18}O_2$ requires C, 85.2; H, 5.3%); λ_{max}(EtOH)/nm 319 (ε/dm^3 mol^{-1} cm^{-1} 12 912), 237.5 (48 006) and 216.5 (39 374); ν_{max}/cm^{-1} 3460–3000 (OH), 2910 (CH_2), 1610 and 1515 (aromatic), 1240 (OH) and 820 (*para*-substituted aromatic); δ_H (300 MHz; DMSO) 3.43 (4 H, s, $2 \times CH_2$), 6.37 and 6.71 (each 4 H, d, *J* 8.4, $4 \times$ Ar-*H*), 7.27 and 7.38 (each 2 H, d, *J* 6.9, $2 \times$ Ar-*H*), 9.09 (2 H, s, $2 \times OH$) (disappears on addition of D_2O); δ_C (75.5 MHz; DMSO) 29.9 (CH_2), 113.9, 119.5, 130.4 and 131.9 (Ar-*C*H), 133.0, 136.2, 140.7, 145.3, 155.4 and 155.5 (Ar-*C*); *m*/*z* (CI) 339 (MH^+, 89), 356 (MNH_4^+, 100%); *m*/*z* (EI) 338.1316 (M^+, $C_{24}H_{18}O_2$ requires 338.1308).

5,6-Bis[4-(prop-2-enyloxy)phenyl]acenaphthene 9

A mixture of diol **8** (0.338 g, 1 mmol), potassium carbonate (0.691 g, 5 mmol), allyl bromide (0.605 g, 5 mmol) and acetonitrile (15 cm^3) was heated under reflux under argon for 20 h. After partial evaporation, the mixture was extracted into ethyl acetate (50 cm^3), washed with dilute hydrochloric acid (25 cm^3), water (25 cm^3), dried ($MgSO_4$) and evaporated. The resulting crude oil was purified by silica gel chromatography (ethyl acetate–*n*-hexane, 1 : 10 as eluent) to give a crude solid which was recrystallised (ethyl acetate, *n*-hexane) to give diether **9** as light yellow crystals (0.364 g, 87%), mp 112–113 °C (Found: C, 86.4; H, 6.1. $C_{30}H_{26}O_2$ requires C, 86.1; H, 6.2%); λ_{max}(EtOH)/nm 310.4 (ε/dm^3 mol^{-1} cm^{-1} 13 289), 235.8 (50 041) and 214.8 (39 822); ν_{max}/cm^{-1} 3400 (Ar–CH), 2340–2440 (CH_2), 1650 (C=C), 1610, 1570 and 1510 (aromatic), 1025 (C–O), 100 and 920 (HC=CH_2) and 820 (*para*-substituted benzene ring); δ_H (300 MHz; $CDCl_3$) 3.48 (4 H, s, $2 \times CH_2$), 4.43 (4 H, d, *J* 5.2, $2 \times CH_2$), 5.29 (2 H, d, *J* 10.5, $2 \times$ alkene C*H*), 5.40 (2 H, dd, *J* 17.8 and 1.5, $2 \times$ alkene C*H*), 6.05 (2 H, m, $2 \times$ alkene C*H*), 6.49 (4 H, d, *J* 8.6, $4 \times$ Ar-*H*), 6.82 (4 H, d, *J* 8.6, $4 \times$ Ar-*H*), 7.37 (4 H, s, $4 \times$ Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 30.1 (CH_2), 68.8 (*C*H-O), 113.3 (*C*H=CH_2), 117.3 (CH=*C*H_2), 119.1, 130.6, 131.7 and 133.5 (Ar-*C*H), 127.8, 135.1, 135.9, 140.5, 149.8 and 156.6 (Ar-*C*); FAB *m*/*z* (relative intensity) 418 (M^+, 100%); EI *m*/*z* 418.1934 (M^+, $C_{30}H_{26}O_2$ requires 418.1933).

5,6-Bis(4-acetoxy-3-prop-2-enylphenyl)acenaphthene 11

A suspension of diether **9** (0.125 g, 0.3 mmol) in dry diphenyl ether (5 cm^3) was degassed by passing an argon stream through the suspension for 5 minutes. The mixture was then heated to reflux for 0.5 h, cooled to room temperature and treated with acetic anhydride (1 cm^3) and triethylamine (1 cm^3). After 12 h, the solution was evaporated *in vacuo* (125 °C, 0.1 mmHg) and purified by silica gel chromatography (petroleum ether–ethyl acetate, 25 : 1, as eluent) to yield diacetate **11** (0.110 g, 73%) as a waxy solid, mp 133 °C (Found: C, 81.4; H, 5.9. $C_{34}H_{30}O_4$ requires C, 81.3; H, 6.0%); λ_{max}(Et_2O)/nm 312.0 (ε/dm^3 mol^{-1} cm^{-1} 16 452), 237.5 (54 698) and 208 (51 726); ν_{max}/cm^{-1} (KBr disc) 3020 (Ar–H), 2980–2840 (CH_3, CH_2, CH), 1770 [Ar–OC(O)CH_3], 1600 and 1500 (aromatic), 1370 (CH_3), 1200 (Ar–O–C), 920 (alkene H) and 850 (*para*-substituted aromatic); δ_H (300 MHz; $CDCl_3$) 2.27 (6 H, s, $2 \times CH_3$), 2.85–3.30 (4 H, br m, $2 \times CH_2$), 3.48 (4 H, s, $2 \times CH_2$), 4.91–5.09 (4 H, br m, $2 \times$ alkene CH_2), 5.65–5.86 (2 H, br s, $2 \times$ alkene C*H*), 6.55–7.11 (6 H, br m, $6 \times$ Ar-*H*) and 7.38 (4 H, s, $4 \times$ Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 20.7 (CH_3), 30.0 (CH_2), 102.6 (CH_2–CH=), 115.9 (=CH_2), 119.1 (*C*H=CH_2), 120.9, 132.1 and 135.9 (Ar-*C*H), 128.1, 131.6, 135.1, 139.9, 140.3, 146.9 and 146.0 (Ar-*C*) and 168.9 (*C*=O); *m*/*z* (EI) 502.4 (M^+, 23), 460.4 ($M^+ - C_2H_3O$, 33) and 418 ($M^+ - C_4H_6O_2$, 45%); *m*/*z* (ES) 520.2499 (M + NH_4, $C_{34}H_{30}O_4$ requires 520.2488).

5,6-Bis(4-methoxy-3-methylphenyl)acenaphthene 12

A mixture of 5,6-dibromoacenaphthene **3** (1.0 g, 3.205 mmol), boronic acid **15** (1.17 g, 7.05 mmol), barium hydroxide octahydrate (4.03 g, 0.0128 mol), *N*,*N*-dimethylacetamide (25 ml) and H_2O (5 ml) was thoroughly degassed before the addition of $Pd(PPh_3)_4$ (0.29 g, 0.256 mmol) under argon. The mixture was heated at 80 °C for 48 h, before quenching with 10% hydrochloric acid (2 cm^3). The resulting mixture was extracted with dichloromethane (2×10 cm^3); the organic phase was washed with dilute hydrochloric acid (10 $cm^3 \times 4$), dried ($MgSO_4$) and evaporated. Purification by silica gel chromatography (diethyl ether–petroleum ether, 3 : 500 as eluent) gave compound **12** (0.813 g; 64%), mp 178 °C (Found: C, 85.1; H, 6.8. $C_{28}H_{26}O_2$ requires C, 85.3; H, 6.6%); λ_{max}(Et_2O)/nm 311.2 (ε/dm^3 mol^{-1} cm^{-1} 13 842), 236.9 (48 818) and 216.3 (49 548); ν_{max}/cm^{-1} 3100–2830 (CH_3, CH_2), 1610 and 1510 (aromatic),

1440 (CH_3, CH_2), 1040 (C–O–C), 850 (isolated aromatic H) and 810 (*para*-substituted aromatic); δ_H (300 MHz; $CDCl_3$) 1.95 and 2.02 (each 3 H, br s, CH_3), 3.50 (4 H, s, 2 × CH_2), 3.78 (6 H, s, 2 × OCH_3), 6.28–7.03 (6 H, br m, 6 × Ar-*H*), 7.37 and 7.40 (each 2 H, d, *J* 7.2, 2 × Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 16.3 (*C*H_3), 30.6 (*C*H_2), 55.7 (O*C*H_3), 109.1, 119.4, 128.0, 131.8 and 132.6 (Ar-*C*H), 128.4, 135.1, 136.7, 140.8, 145.9 and 156.1 (Ar-*C*); *m*/*z* (CI) 412 ($M + NH_4^+$, 100), 395 (MH^+, 80) and 32 (CH_3OH^+, 53%); *m*/*z* (EI) 394.1940 (M^+, $C_{28}H_{26}O_2$ requires 394.1933).

5,6-Bis(3-*tert*-butyl-4-methoxyphenyl)acenaphthene 13

A mixture of 5,6-dibromoacenaphthene **3** (1.0 g, 3.205 mmol), boronic acid **16** (1.46 g, 7.40 mmol), barium hydroxide octahydrate (5.86 g, 0.0128 mol), *N*,*N*-dimethylacetamide (25 cm^3) and H_2O (5 cm^3) was thoroughly degassed using the freeze–pump–thaw method (three cycles) before the addition of $Pd(PPh_3)_4$ (0.29 g, 0.256 mmol); this was then degassed again using the same method (three cycles) then heated at 80 °C for 48 h under argon. The resultant mixture was cooled and dichloromethane (25 cm^3) added, the organic phase was washed with dilute hydrochloric acid (25 cm^3 × 4) and dried over $MgSO_4$. Concentration of the organic phase *in vacuo,* followed by silica gel chromatography (petroleum ether–ethyl acetate, 250 : 1, as an eluent) gave **13** (1.17 g, 78%), mp 212–216 °C (Found: C, 85.0; H, 8.1. $C_{34}H_{38}O_2$ requires C, 85.3; H, 8.1%); $\lambda_{max}(Et_2O)$/nm 317.2 (ε/dm^3 mol^{-1} cm^{-1} 14 480), 238.2 (49 862) and 215.4 (51 775); ν_{max}/cm^{-1} 3050–2740 (CH_3, CH_2), 1610 and 1500 (aromatic), 1390 [C(CH_3)$_3$], 1030 (C–O–C), 850 (isolated Ar-H) and 810 (*para*-substituted aromatic ring); δ_H (300 MHz; $CDCl_3$) 1.26 [18 H, s, 2 × C(CH_3)$_3$], 3.51 (4 H, s, 2 × CH_2), 3.76 (6 H, s, 2 × OCH_3), 6.53 (2 H, d, *J* 8.3, 2 × Ar-*H*), 6.88 (2 H, s, 2 × Ar-*H*), 6.91 (2 H, s, 2 × Ar-*H*), 7.40 (4 H, s, 4 × Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 30.0 [C(*C*H_3)$_3$], 30.5 (*C*H_2), 34.9 [*C*(CH$_3$)$_3$], 55.0 (O*C*H_3), 110.9, 119.5, 128.2, 128.5 and 132.6 (Ar-*C*H), 135.1, 136.3, 137.2, 141.0, 145.8 and 156.7 (Ar-*C*); *m*/*z* (CI) 496 ($M + NH_4^+$, 80), 479 (MH^+, 70), 423 ($M^+ - C_4H_8$, 20) and 391 ($M^+ - C_5H_{11}O$, 35%); *m*/*z* (EI) 478.2876 (M^+, $C_{34}H_{38}O_2$ requires 478.2872).

5,6-Bis(3-*tert*-butyl-5-methyl-4-methoxyphenyl)acenaphthene 14

A mixture of 5,6-dibromoacenaphthene **3** (0.50 g, 1.602 mmol), boronic acid **17** (0.818 g, 3.68 mmol), barium hydroxide octahydrate (2.93 g, 6.408 mmol), *N*,*N*-dimethylacetamide (15 cm^3) and H_2O (3 cm^3) was exhaustively degassed using a pump–freeze–thaw cycle (3×) and placed under an argon atmosphere, before the addition of $Pd(PPh_3)_4$ (0.184 g, 0.160 mmol). The mixture was heated at 80 °C for 24 h, before quenching with 10% hydrochloric acid (5 cm^3). The resulting mixture was extracted with dichloromethane (25 cm^3 × 2), the organic phase was washed with dilute hydrochloric acid (25 cm^3 × 4), dried ($MgSO_4$) and evaporated. Purification by silica gel chromatography (hexane as an eluent) gave two fractions. Fraction one was the mono-coupled product, 5-bromo-6-(3-*tert*-butyl-5-methyl-4-methoxyphenyl)acenaphthene (0.254 g, 48%), mp 156 °C (decomposes); $\lambda_{max}(Et_2O)$/nm 302 (ε/dm^3 mol^{-1} cm^{-1} 6209) and 203 (35 634); δ_H (300 MHz; $CDCl_3$) 1.51 [9 H, s, C(CH_3)$_3$], 2.48 (3 H, s, CH_3), 3.48 (3 H, s, OCH_3), 3.92 (4 H, s, 2 × CH_2), 7.28–7.51 (6 H, m, 6 × Ar-*H*), 7.79 (1 H, s, Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 17.9 (*C*H_3), 30.4 and 31.0 (*C*H_2), 31.6 [C(*C*H_3)$_3$], 35.6 [*C*(CH$_3$)$_3$], 61.1 (O*C*H_3), 119.5, 119.6, 121.5, 126.9, 128.3, 128.8 and 131.4 (Ar-*C*H), 130.3, 131.5, 135.4, 136.3, 140.0, 142.6, 145.5, 146.6 and 158.0 (Ar-*C*); *m*/*z* (FAB) 329 ($M^+ - H$, 85), 273 ($M^+ - C_4H_9$, 35), 57 ($C_4H_9^+$, 100%). Fraction two was di-coupled compound **14** (0.358 g; 44%), mp 208–210 °C (Found: C, 85.4; H, 8.7. $C_{36}H_{42}O_2$ requires C, 85.3; H, 8.3%); $\lambda_{max}(Et_2O)$/nm 318.4 (ε/dm^3 mol^{-1} cm^{-1} 15 498), 239.2 (59 320) and 212.0 (71 845); ν_{max}/cm^{-1} (KBr disc) 3040–2780 (CH_3, CH_2), 1600 and 1480 (aromatic), 1410 (CH_2, CH_3), 1140 (C–O–C), 880 (isolated aromatic H) and 840 (*para*-substituted aromatic); δ_H (300 MHz; $CDCl_3$) 1.27 [18 H, s, 2 × C(CH_3)$_3$], 2.20 (6 H, s, 2 × CH_3), 3.51 (4 H, s, 2 × CH_2), 3.70 (6 H, s, 2 × OCH_3), 6.84 (2 H, s, 2 × Ar-*H*), 6.87 (2 H, s, 2 × Ar-*H*), 7.40 (4 H, s, 4 × Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 18.0 (*C*H_3), 30.5 (*C*H_2), 31.3 [C(*C*H_3)$_3$], 35.0 [*C*(CH$_3$)$_3$], 60.7 (O-*C*H_3), 119.6, 126.5, 130.9 and 133.0 (Ar-*C*H), 127.5, 129.9, 136.9, 137.9, 141.0, 141.3, 145.9 and 156.8 (Ar-*C*); *m*/*z* (CI) 524 ($M + NH_4^+$, 100%), 507 (MH^+, 15%); *m*/*z* (EI) 506.3187 (M^+, $C_{36}H_{42}O_2$ requires 506.3185).

5,6-Bis(3-*tert*-butyl-4-hydroxyphenyl)acenaphthene 18

A solution of bis(methyl ether) **13** (0.1066 g, 0.22 mmol) in dry dichloromethane (10 cm^3) under argon at −78 °C was treated with boron tribromide (0.56 cm^3, 1 M solution in dichloromethane), dropwise. The resulting red solution was warmed to room temperature. After 3 h, the reaction was quenched with dilute hydrochloric acid (2 cm^3), and the mixture was partially evaporated, partitioned between ethyl acetate (20 cm^3) and dilute hydrochloric acid (20 cm^3), dried ($MgSO_4$) and evaporated to give an oil. Purification by silica gel chromatography (ethyl acetate–petroleum ether, 1 : 5 as eluent) gave **18** as a white solid (0.0733 g, 73%), mp 101–103 °C (decomp.) (Found: C, 81.8; H, 7.8. $C_{32}H_{34}O_2 \cdot H_2O$ requires C, 82.1; H, 7.8%); $\lambda_{max}(Et_2O)$/nm 322.5 (ε/dm^3 mol^{-1} cm^{-1} 20 019), 241.5 (53 793) and 215 (57 954); ν_{max}/cm^{-1} (thin film) 3590–3100 (OH), 3000–2820 (CH_2, CH_3), 1610 and 1510 (aromatics), 1410 (O–H), 1390 (CH_3), 1350 ($COCH_3$), 1260 (Ar-O–C), 1110 (C–O) and 820 (*para*-substituted aromatic ring); δ_H (300 MHz; $CDCl_3$) 1.24 [18 H, s, 2 × C(CH_3)$_3$], 3.50 (4 H, s, 2 × CH_2), 4.67 (2 H, br s, 2 × O*H*) (signals disappear on addition of D_2O), 6.46 and 6.99 (each 2 H, d, *J* 7.9, 2 × Ar-*H*), 6.69 (2 H, br s, 2 × Ar-*H*) and 7.37 (4 H, s, 4 × Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 29.7 [C(*C*H_3)$_3$], 30.5 (*C*H_2), 34.6 [*C*(CH$_3$)$_3$], 116.4, 119.5, 127.7 129.5 and 132.8 (Ar-*C*H), 128.8, 134.1, 135.7, 137.0, 140.6, 145.9 and 152.6 (Ar-*C*); *m*/*z* (FAB) 450 (M^+, 100), 393 ($M^+ - C_4H_9$, 9%); *m*/*z* (EI) 450.2561 (M^+, $C_{32}H_{34}O_2$ requires 450.2559).

5,6-Bis(4-benzyloxy-3-*tert*-butylphenyl)acenaphthene 19

To a solution of diphenol **18** (0.0437 g, 0.097 mmol) in dry THF (2 cm^3) was added benzyl bromide (0.0498 g, 0.29 mmol) and sodium hydride (0.0070 g, 0.29 mmol). The mixture was heated under reflux for 4 h, cooled, quenched with dilute hydrochloric acid (0.5 cm^3) and evaporated. The resulting oil was purified by silica gel chromatography (ethyl acetate–petroleum ether, 1 : 300 as eluent) to yield an impure oil (0.0053 g), which was further purified by preparative TLC (1000 μm) to yield bis(benzyl ether) **19** (0.010 g, 16%); δ_H (200 MHz; $CDCl_3$) 1.29 (18 H, s, 2 × CMe_3), 3.49 (4 H, s, CH_2CH_2), 4.97 (4 H, s, 2 × PhCH_2), 6.57 (2 H, d, *J* 8.3, 2 × BnO–C–C*H*), 6.88 (2 H, dd, *J* 8.3 and 1.4, 2 × BnO–C–CH–C*H*), 6.96 (2 H, d, *J* 1.4, 2 × ^{t}Bu–C–C*H*), 7.38–7.32 (14 H, m, 2 × Ph + acenaphtheneH); δ_C (100 MHz; $CDCl_3$) 28.7, 29.1, 33.6, 68.9, 110.4, 118.1, 126.3, 126.6, 126.9, 127.2, 127.4, 131.2, 131.3, 134.0, 135.0, 135.3, 135.6, 136.6, 144.5, 154.5; FAB *m*/*z* (relative intensity) 631 [($M + H^+$), 100%]; EI *m*/*z* 630.3503 (M^+, $C_{46}H_{46}O_2$ requires 630.3498).

Mono-*O*-Me-mandelate ester 20

To a solution of diphenol **18** (0.012 g, 0.027 mmol) in anhydrous dichloromethane (2 cm^3) was added (*S*)-(+)-α-methoxyphenylacetic acid (0.098 g, 0.058 mmol), 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDCI) (0.011 g, 0.058 mmol) and DMAP (0.072 g, 0.058 mmol). The resulting suspension was stirred at room temperature for 24 h, partially evaporated and partitioned between ethyl acetate (10 cm^3) and water (5 cm^3). The organic phase was washed with saturated aqueous sodium bicarbonate solution

(5 cm^3), dried ($MgSO_4$) and evaporated. Purification of the resulting oil by neutral alumina chromatography (petroleum ether–dichloromethane, 1 : 2 as eluent) gave mono ester **20** as a mixture of diastereoisomers (0.07 g, 44%): ν_{max}(KBr disc)/cm^{-1} 3420, 2982, 1720, 1609; δ_H (400 MHz; $CDCl_3$) 1.08, 1.12, 1.16 and 1.26 (each 9 H, s, 4 × ^tBu), 1.29 (18 H, s, 2 × ^tBu), 3.47 (12 H, s, 3 × CH_2CH_2), 3.52 (6 H, s, 2 × OMe), 3.53 (3 H, s, OMe), 4.88, 5.00 and 5.19 (each 1 H, br s, signals disappear on addition of D_2O, 3 × OH), 4.97 (1 H, s, MeO–C*H*), 4.98 (2 H, s, 2 × MeO–C*H*), 6.18, 6.25, 6.29, 6.38 (each 1 H, d, *J* 8.0, 4 × ArH), 6.53–6.57 (3 H, m, 3 × ArH), 6.67–6.69 (2 H, m, 2 × ArH), 6.73–6.76 (3 H, m, 3 × ArH), 6.86, 6.89 and 6.99 (each 1 H, d, *J* 2.0, 3 × ArH), 7.28–7.45 (25 H, m, 25 × ArH), 7.52–7.56 (5 H, m, 5 × ArH); DEPT135 NMR δ_C (100 MHz; $CDCl_3$) 29.8 (CH_3), 30.0 (CH_3), 30.1 (CH_2), 30.2 (CH_3), 30.5 (CH_3), 30.6 (CH_2), 57.8 (OCH_3), 58.1 (OCH_3), 77.6 (CH), 83.4 (CH), 83.5 (CH), 117.3 (CH), 117.6 (CH), 119.4 (CH), 119.5 (CH), 119.6 (CH), 121.9 (CH), 122.3 (CH), 127.8 (CH), 128.1 (CH), 128.3 (CH), 128.4 (CH), 128.6 (CH), 128.9 (CH), 129.0 (CH), 129.2 (CH), 129.4 (CH), 129.5 (CH), 132.5 (CH), 132.8 (CH), 132.9 (CH); FAB *m*/*z* (relative intensity) 598 (M^+, 13%), 121 ($C_8H_9O^+$, 100%), 57 ($C_4H_9^+$); *m*/*z* (EI) 593.3088 (M^+, $C_{41}H_{42}O_4$ requires 598.3083).

4,6-Bis(3-*tert*-butyl-4-hydroxyphenyl)acenaphthene 21

A solution of bis(methyl ether) **13** (0.10 g, 0.21 mmol) in dry dichloromethane (15 cm^3) under argon at −78 °C was treated with boron tribromide solution (0.21 cm^3 of a 2.0 M solution in dichloromethane, 0.421 mmol) (slow addition) and the mixture allowed to warm to rt. After 12 h, the reaction was quenched with 10% HCl; the product was partially evaporated, diluted with ethyl acetate, washed with 10% HCl, dried ($MgSO_4$) and evaporated. The resulting solid was purified by silica gel chromatography (petroleum ether–ethyl acetate, 100 : 1 as eluent) to give diphenol **18** (0.044 g, 46%) which was identical to that reported (*vide supra*) and rearrangement product **21** (0.022 g, 23%), mp 91 °C; λ_{max}(Et_2O)/nm 321.0 (ε/dm^3 mol^{-1} cm^{-1} 12 061), 272 (30 397) and 212 (35 403); ν_{max}/cm^{-1} (thin film) 3680–3160 (OH), 3020–2910 (CH_3, CH_2), 2890 (Ar–H), 1610 and 1500 (aromatic), 1470 (CH_3), 1260 (C–OH), 1090 (C–O) and 820 (*para*-substituted aromatic); δ_H (300 MHz; $CDCl_3$) 1.45 and 1.47 [each 9 H, s, C(CH_3)$_3$], 3.40 and 3.43 (each 2 H, s, CH_2), 4.81 and 4.84 (each 1 H, s, O*H*) (signals disappear on addition of D_2O), 6.72 (1 H, d, *J* 8.3, Ar-*H*), 6.78 (1 H, d, *J* 7.9, Ar-*H*), 7.26–7.36 (3 H, m, 3 × Ar-*H*), 7.40 (1 H, d, *J* 7.2, Ar-*H*), 7.51 (1 H, br s, Ar-*H*), 7.53 and 7.54 (each 1 H, d, *J* 4.5, Ar-*H*) and 7.85 (1 H, s, Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 30.0 and 30.1 [C(CH_3)$_3$], 30.6 and 31.0 (CH_2), 35.1 [C(CH_3)$_3$], 116.9, 117.2, 119.3, 119.5, 119.7, 126.6, 127.0, 128.5, 129.1 and 129.2 (Ar-CH), 130.3, 133.0, 135.3, 136.3, 136.4, 136.6, 139.1, 142.0, 145.1, 147.1, 153.9 and 154.2 (Ar-*C*); *m*/*z* (FAB) 450 (M^+, 100%); *m*/*z* (EI) 450.2564 (M^+, $C_{32}H_{34}O_2$ requires 450.2559).

5,6-Bis(4-hydroxy-3-methylphenyl)acenaphthene 23

To a solution of bis(methyl ether) **12** (0.27 g, 0.68 mmol) in dry dichloromethane (10 cm^3) under argon at −78 °C, boron tribromide (1.4 cm^3 of a 1 M solution in dichloromethane) was added slowly, then the mixture was allowed to warm to room temperature. After five hours the reaction was quenched with 10% HCl solution (10 cm^3); the product was evaporated, extracted into ethyl acetate, washed with 10% HCl, dried ($MgSO_4$) and evaporated. The crude product was then recrystallised from diethyl ether–hexane to yield **23** (0.18 g, 73%) as a light brown solid, mp 203 °C (decomp.); λ_{max}(EtOH)/nm 315.0 (ε/dm^3 mol^{-1} cm^{-1} 12 115), 238 (38 730) and 203.5 (48 038); ν_{max}/cm^{-1} (KBr disc) 3460–3080 (OH), 3010–2930 (CH_2, CH_3), 1600 and 1500 (aromatic), 1430 (CH_3, CH_2), 1350 (OH), 1150 (C–O), 880 (isolated aromatic H) and 820 (*para*-substituted ring); δ_H (300 MHz; DMSO) 1.61–2.01 (6 H, br s, 2 × CH_3), 3.39 (4 H, s, 2 × CH_2), 6.08–6.89 (6 H, br m, 6 × Ar-*H*), 7.24 and 7.33 (each 2 H, d, *J* 7.2, 2 × Ar-*H*) and 8.88 (2 H, s, 2 × O*H*) (signal disappears on addition of D_2O); δ_C (75.5 MHz; DMSO) 16.1 (CH_3), 29.9 (CH_2), 113.3, 119.3, 127.1, 131.5 and 132.1 (Ar-*C*H), 122.1, 127.5, 132.9, 136.6, 140.5, 145.1 and 153.6 (Ar-*C*); *m*/*z* (CI) 366 (M^+, 100%); *m*/*z* 366.1622 (M^+, $C_{26}H_{22}O_2$ requires 366.1620).

5,6-Bis(3-*tert*-butyl-4-hydroxy-5-methylphenyl)acenaphthene 24 and 4,6-bis(3-*tert*-butyl-4-hydroxy-5-methylphenyl)-acenaphthene 25

To a solution of **14** (0.112 g, 0.221 mmol) in dichloromethane (10 cm^3), under argon, at −78 °C a solution of boron tribromide (0.44 cm^3 of a 1 M solution in DCM) was slowly added, then the temperature was allowed to increase to room temperature. After 12 hours the reaction was quenched with 10% HCl solution (10 cm^3); the product was evaporated, extracted into ethyl acetate, washed with 10% HCl, dried ($MgSO_4$) and evaporated. The resulting solid (0.100 g) was purified by silica gel chromatography (petroleum ether–ethyl acetate, 10 : 1 as eluent) to yield diphenol **24** as the first fraction (0.024 g, 23%); δ_H (300 MHz; $CDCl_3$) 1.17 [18 H, s, 2 × C(CH_3)$_3$], 2.21 (6 H, s, 2 × CH_3), 3.49 (4 H, s, 2 × CH_2), 4.55 (2 H, s, 2 × O*H*) (signal disappears on addition of D_2O), 6.55 (2 H, s, 2 × Ar-*H*), 7.02 (2 H, s, 2 × Ar-*H*), 7.37 (4 H, s, 4 × Ar-H); δ_C (75.5 MHz; $CDCl_3$) 16.5 (CH_3), 29.7 [C(CH_3)$_3$], 30.5 (CH_2), 34.4 [C(CH_3)$_3$], 119.5, 127.6, 129.6 and 133.1 (Ar-*C*H), 122.1, 133.8, 135.2, 137.0, 141.0, 145.9 and 151.1 (Ar-*C*); *m*/*z* (CI) 478 (M^+, 100), 57 ($C_4H_9^+$, 87%); *m*/*z* (EI) 478.2871 (M^+, $C_{34}H_{38}O_2$ requires 478.2872). The second fraction was rearrangement product **25** (0.013 g, 12%), δ_H (300 MHz; $CDCl_3$) 1.49 and 1.51 [each 9 H, s, C(CH_3)$_3$], 2.33 and 2.36 (each 3 H, s, CH_3), 3.40–3.57 (4 H, br s, 2 × CH_2), 4.82 and 4.86 (each 1 H, s, O*H*) (signal disappears on addition of D_2O), 7.25–7.26 (1 H, m, Ar-*H*), 7.29–7.34 (1 H, br m, Ar-*H*), 7.35–7.49 (4 H, br m, 4 × Ar-*H*), 7.53 (1 H, s, Ar-*H*) and 7.91 (1 H, s, Ar-*H*); δ_C (75.5 MHz; $CDCl_3$) 16.0 and 16.6 (CH_3), 29.7 and 30.3 [C(CH_3)$_3$], 30.6 and 31.0 (CH_2), 35.1 [C(CH_3)$_3$], 119.2, 119.6, 124.9, 127.2, 128.3, 129.1, 130.1 and 133.2 (Ar-*C*H), 123.4, 123.6, 130.3, 132.4, 134.6, 135.8, 136.1, 136.4, 139.1, 142.0, 145.0, 147.0, 152.3 and 152.6 (Ar-*C*); *m*/*z* (CI) 478 (M^+, 80), 57 ($C_4H_9^+$, 100%); *m*/*z* (EI) 478.2863 (M^+, $C_{34}H_{38}O_2$ requires 478.2871).

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