Substituent effects in the induction of a cholesteric liquid crystal phase by atropisomeric dibenzoxepins: a study of arene–arene interactions

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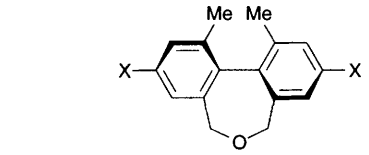
Substituent effects in the induction of a cholesteric liquid crystal phase by atropisomeric dibenzoxepins suggest that both electrostatic repulsion and polarizability are important factors controlling the stability of arene π-stacking complexes.

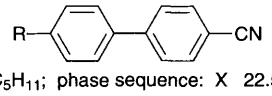
The propensity of aromatic molecules to aggregate in a face-to-face orientation (π-stacking) is of considerable importance in the stabilization of many supramolecular structures found in biological systems[1] and host–guest inclusion complexes.[2] These interactions have often been characterized as charge-transfer (CT) or electron donor–acceptor (EDA) complexes, although there is increasing experimental evidence that the formation of these complexes is controlled primarily by electrostatic interactions and dispersive forces, and not by the overlap of frontier molecular orbitals.[3,4] Recent studies[3] of the π-stacking complexes of substituted arenes have drawn correlations between the stability of the complexes and the electron-withdrawing character of the substituents, thus providing some of the strongest evidence in favour of the electrostatic interaction model. However, these studies do not take into account the effect of substituents on the polarizability of arenes as a possible contributing factor. In order to address this issue, and to provide further experimental evidence regarding the nature of π-stacking interactions, we have undertaken a systematic study of substituent effects in the induction of a twisted nematic (cholesteric) liquid crystal phase by C_2-symmetric atropisomeric biaryl dopants.

The addition of a chiral dopant to a nematic liquid crystal induces a macroscopic helical twist with a pitch that is a function of the dopant concentration and the propensity of the dopant to induce a helical twist, the helical twisting power (β_M).[5] When the chiral dopant is a C_2-symmetric atropisomeric biaryl, Gottarelli and Solladié have shown that the helical sense of the induced cholesteric phase can be correlated to that of the dopant, with the highest β_M values usually recorded in biphenyl nematic hosts.[6] Such correlation, along with linear dichroism experiments showing the twofold symmetry axis of biaryl dopants to orient perpendicular to the nematic director,[7] led to the hypothesis that cholesteric induction takes place *via* conformational interactions that are π-facial in nature, and suggests that β_M should be a function of the stability of dopant–host π-stacking interactions. In this communication, we report β_M values for the atropisomeric dibenzoxepins **1a–e** in the biphenyl nematic hosts **K15** and **M15**, and in the phenylpyrimidine nematic host **PhPy** at a fixed temperature difference below the clearing point. The observed trend in β_M values is rationalized in terms of variations in the electron-withdrawing character of substituents X and their influence on the polarizability of the dopant.

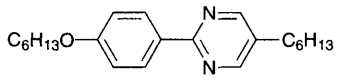
The atropisomeric dibenzoxepins **1a–e** were obtained *via* a modification of the route described by Wittig and Zimmermann,[8] as shown in Scheme 1, using 2-iodo-3-methyl-5-nitrobenzoic acid **2**[9] as the starting material.‡ Dopants **1a**, **1d** and **1e** were obtained in optically pure form *via* classical resolution of the diphenic acid **3** using quinine. Dopants **1b** and **1c** were obtained in optically pure form *via* chiral stationary phase HPLC resolution of the racemates using a Regis (*S,S*)-Whelk-O 1 column.§ The nematic hosts **K15** and **M15** were obtained from Aldrich and **PhPy** was synthesized according to the literature procedure.[10] Dopant–host mixtures were prepared at concentrations ranging from 0.5 to 4.5 mol% to give induced cholesteric phases. The pitch (p) of each cholesteric phase was measured by polarized microscopy at a temperature difference of 5 °C below the clearing point using the 'droplet' method,[11]



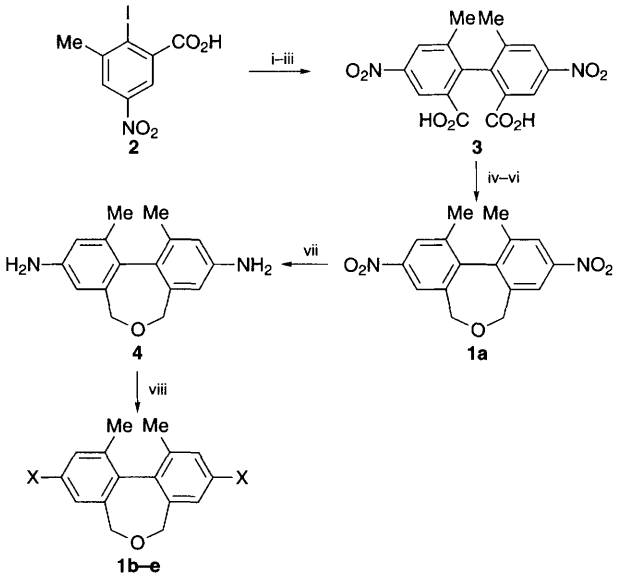
1a X = NO_2
b X = Br
c X = Cl
d X = NMe_2
e X = H



K15 R = C_5H_{11}; phase sequence: X 22.5 N 35 I
M15 R = $C_5H_{11}O$; phase sequence: X 48 N 67 I



PhPy; phase sequence: X 31 N 60 I



Scheme 1 *Reagents and conditions*: i, H_2SO_4, MeOH, reflux, 96%; ii, Cu, DMF, reflux, 65%; iii, NaOH, 1 : 1 EtOH–H_2O, reflux, 73%; iv, quinine (1 equiv.), EtOH, reflux, then 6 M HCl (> 98% ee); v, BH_3·THF, 25 °C, 86%; vi, toluene-*p*-sulfonic acid, C_6H_6, reflux with Dean–Stark trap, 70%; vii, $SnCl_2$·H_2O, EtOH, reflux, 94%; viii, (**1b**) $NaNO_2$, 48% HBr, 0 °C, then CuBr, 25 °C, 49%, (**1c**) $NaNO_2$, 6 M HCl, 0 °C, then CuCl, 25 °C, 33%, (**1d**) CH_2O, $NaBH_3CN$, MeCN, then AcOH, 25 °C, 70%, (**1e**) $NaNO_2$, 6 M HCl, 0 °C, then H_3PO_2, 25 °C, 35%

and β_M values were recorded as the slopes of $1/p$ *vs.* [dopant] plots.

The β_M values for dopants **1a–e** are shown in Table 1 along with Hammett σ_p constants for substituents X, and polarizability values (α) for the corresponding substituted benzenes.¶ Examination of Table 1 reveals that the trend in β_M values cannot be correlated with either the Hammett σ_p values or with the polarizability values. However, there appears to be a qualitative agreement between the trend in β_M values and that predicted by σ_p and α values taken together. Hence, although dopant **1d** would be expected to exhibit the weakest π-stacking interaction based on electrostatic repulsion alone, its β_M value is greater than that of the unsubstituted dopant **1e** by virtue of the high polarizability conferred by the dimethylamino group. At the other end of the scale, the high β_M values recorded for **1a** can be readily ascribed to the electron-withdrawing character of the nitro group, whereas the higher than expected β_M values recorded for **1b** and **1c** may be ascribed to both the polarizability and electron-withdrawing character of the halide substituents.

As the three nematic hosts used in this study have aromatic cores that are relatively electron-rich, we cannot rule out the possible contribution of charge-transfer interactions to the π-stacking complexes considered thus far. It is also possible that steric effects contribute to the observed variations in β_M values, although the trend shown in Table 1 is inconsistent with that being a dominant factor. Further work aimed at ruling out CT and steric effect contributions in these systems is in progress. With the assumption that chirality transfer in the induced cholesteric phases described herein does proceed *via* π-facial conformational interactions, the data shown in Table 1 suggests that *both* electrostatic repulsion and polarizability are important factors controlling the stability of arene π-stacking complexes.

Table 1 β_M Values for dopants **1a–e** in the nematic hosts **K15**, **M15** and **PhPy**

	$\beta_M/\mu m^{-1}$ [a]				
Dopant	**K15**	**M15**	**PhPy**	σ_p	$\alpha/10^{-23}$ cm^3
1a	20.3 ± 0.3	9.9 ± 0.5	15.6 ± 0.1	0.78	1.30
1b	19.3 ± 0.5	11.6 ± 0.4	10.8 ± 0.5	0.23	1.35
1c	17.2 ± 0.5	10.3 ± 0.5	9.5 ± 0.4	0.23	1.24
1d	4.2 ± 0.1	4.9 ± 0.2	8.2 ± 0.2	−0.83	1.62
1e	0.3 ± 0.1	2.0 ± 0.1	0.2 ± 0.05	0	1.04

[a] Errors are given as standard deviations.

Such considerations may be particularly relevant to the fine tuning of π-stacking interactions *via* permutation of arene substitutents.

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Footnotes

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‡ All new compounds gave satisfactory spectral data (^{1}H, ^{13}C NMR and mass spectra) and combustion analyses.

§ The optical purity (> 98% ee) of compounds **1a–e** was confirmed by ^{1}H NMR using Eu(hfc)$_3$ as chiral shift reagent (**1a**, **1d**, **1e**), and by chiral stationary phase HPLC (**1b**, **1c**).

¶ Polarizability values (α) for benzene, bromobenzene, chlorobenzene, nitrobenzene and *N*,*N*-dimethylaniline were derived from known[12] refractive indexes (n) and density values (ρ) using the Lorenz–Lorenz equation:[13]

$$\alpha = \frac{3}{4\pi N}\left(\frac{n^2-1}{n^2+2}\right)\frac{M_w}{\rho}$$

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