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ARTICLE

Molecular Symmetry and Fluorine-Containing Supramolecular Synthons as Structure-Differentiating Agents in Some "Bridge-Flipped" Isomeric *bis*-Benzylideneanilines

Cite this: DOI: 10.1039/x0xx00000x

Received 00th January 2012,
Accepted 00th January 2012

DOI: 10.1039/x0xx00000x

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The crystal structures of three pairs of "bridge-flipped isomers" are compared here in the context of whether their similarity in molecular space-filling requirements in combination with the tendency of centrosymmetric molecules to occupy crystallographic inversion centers might lead to their isomorphism. The possibility that similar fluorine-based supramolecular synthons occurring in the crystal structures of both members of a pair might promote their isomorphism is also considered. The compounds are the *bis*-benzylideneanilines formed by reaction of 2-fluoroaniline, 3-fluoroaniline, and 4-fluoroaniline respectively with terephthaldehyde (**1**-**3**) and by reaction of 2-fluorobenzaldehyde, 3-fluorobenzaldehyde, and 4-fluorobenzaldehyde respectively with phenylenediamine (**4**-**6**). The crystal structure of **2** is disordered, with the fluorine atom occupying two sites (95:5 occupation) related by rotation about the bond between the bridge nitrogen atom and the 3-fluorophenyl group. The crystal structure of **6** (HEWHAU) has been reported by previous workers. The structures of the **1**:**4**, **2**:**5**, and **3**:**6** pairs are compared to each other and to those of fluorinated simple (one-bridge) benzylideneanilines and fluorinated *bis*-benzylideneanilines recently described in the literature. No isomorphism is found among the bridge-flipped isomeric pairs, and none is found between positional isomers within the **1**-**3** or **4**-**6** series. The supramolecular synthon defined by a 2-F···bridge H contact is found in several of the benzylideneaniline crystal structures, but it does not compel isomorphism, nor is it specific to one type (terephthaldehyde-based or phenylenediamine-based) of isomer. Conformational variability and supramolecular synthon variety apparently serve as structure differentiators, not as isomorphism facilitators, among these *bis*-benzylideneanilines.

1 Introduction

Solid-state molecular packing arrangements are a function of not only intermolecular interactions but also molecular space-filling requirements. To examine the influence of both on the crystal structures of organic compounds, we are conducting a study of the solid-state molecular packing arrangements of pairs of molecules we have designated "bridge-flipped isomers,"[1] isomeric molecules related to each other by the reversal of a bridge or chain of atoms connecting two major portions of each molecule. Such isomerism is displayed by the phenylhydrazones, in which the isomeric relationship is Ar-NH-N=CH-Ar' vs. Ar-CH=N-NH-Ar' (Ar = aryl), and in benzylideneanilines, in which the relationship is Ar-CH=N-Ar' vs. Ar-N=CH-Ar' (Ar = aryl). We are interested in identifying pairs of bridge-flipped isomers that assume identical molecular packing arrangements and form isomorphous crystals. An isomorphous pair would be of interest for their potential ability to form a continuous series of solid solutions in which the conductivity, solubility, or color (an especially conspicuous property of the phenylhydrazones) might be capable of being tailored or engineered to a particular desired state. A non-isomorphous pair would be of interest for the insights it would lend into both the intramolecular factors (such as molecular conformation) and the intermolecular factors (such as intermolecular H-bonding, halogen bonding, or π···π interactions) that differentiate the two crystal structures. The benzylideneanilines and phenylhydrazones are of particular interest to us because in these compounds, unlike other bridge-connected compounds such as esters and amides,[2] the steric differences between the reversed bridges are relatively small and might not interfere with the formation of isomorphous crystals.

In even these two potentially promising families of compounds, we have found isomorphism to be rare, although a few isomorphous pairs are known. In phenylhydrazones, a potential differentiating factor is the presence of a strong, conventional H-bond donor, the N-H bond, in the bridge. If the bridge-flipped isomeric phenylhydrazones bear an H-bond acceptor capable of interacting with this N-H group, then the different position of the

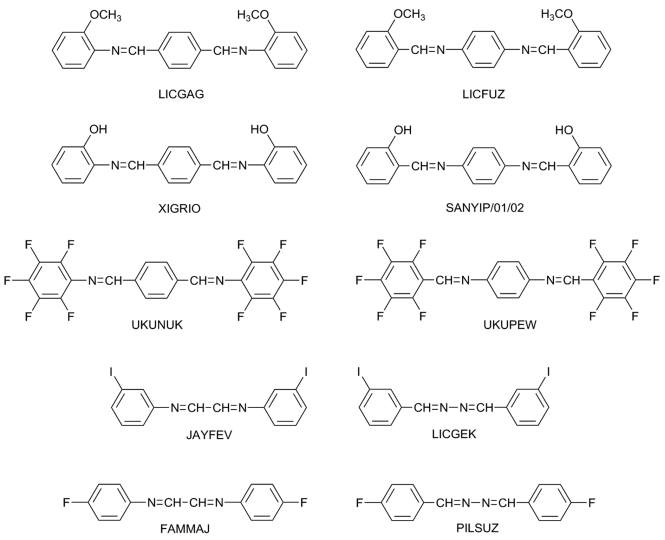

Fig. 1 Some non-isomorphous pairs of centrosymmetric bridge-flipped isomeric *bis*-benzylideneanilines found in the Cambridge Structural Database.

N-H group within the bridge from one isomer to the other is likely to cause significant differences between the isomers in their molecular packing. In the examples of isomorphous bridge-flipped phenylhydrazones we and previous workers have examined to date,[1,3] an H-bond acceptor has indeed been present, but the packing arrangement has placed it roughly equidistant from the N-H and C-H hydrogen atoms in the bridge, with the weak H-bond donor C-H mimicking the strong H-bond donor N-H in these particular cases. In benzylideneanilines, no similar H-bonding difference between bridge-flipped isomers occurs; instead, a conformational difference related to the position of the bridge C-H can exist between the isomers. Steric interaction between the bridge C-H and an *ortho* H-atom on the aniline ring can force the aniline ring farther out of coplanarity with the CH=N bridge atoms than the benzylidene ring. Bridge-flipped isomeric benzylideneanilines affected by this interaction can be expected to possess different conformations and thus assume different molecular packing arrangements. Nonetheless, the crystallographic literature includes examples of benzylideneaniline structures in which the molecules are nearly planar, which suggests to us that the formation of isomorphous crystals of bridge-flipped benzylideneanilines need not in all cases be prohibited by conformational differences. Isomorphous pairs of bridge-flipped benzylideneanilines do occur, with the isomorphism accompanied by end-for-end disorder of the molecules in some cases.[1,4] If two opposite orientations of the molecule can be found at a given site in a disordered benzylideneaniline crystal structure, this suggests to us that the same crystal structure could be assumed independently by two bridge-flipped isomeric benzylideneanilines.

In isomorphous bridge-flipped benzylideneanilines, the occurrence of the end-for-end disorder in one or both members of the isomeric pair generally requires that the molecule(s) be at least *approximately* centrosymmetric. An opportunity for evaluating the role of molecular symmetry in the potential isomorphism of bridge-flipped benzylideneanilines is therefore presented by extending the range of compounds examined from simple (one-bridge) benzylideneanilines to symmetrically substituted *bis*-benzylideneanilines, which are capable of assuming an *exactly* centrosymmetric conformation in the solid state. We are interested in whether the tendency of centrosymmetric molecules to occupy crystallographic centers of symmetry in the solid state,[5] *specifically in combination with a close similarity in molecular size and shape,* would facilitate isomorphism between bridge-flipped *bis*-benzylideneanilines. An examination of the crystallographic literature thus far gives little reason to think so. Non-isomorphous bridge-flipped pairs found in the Cambridge Structural Database[6] (Version 5.34) such as LICGAG and LICFUZ[7], XIGRIO[8] and SANYIP/SANYIP01/SANYIP02[9], UKUNUK and UKUPEW[10], LICGEK[7] and JAYFEV[11], and FAMMAJ[12] and PILSUZ[13] (Fig. 1) offer little encouragement that even genuinely centrosymmetric bridge-flipped isomers can assume isomorphous crystal structures. On the other hand, a general similarity if not actually an exact correspondence between the crystal structures of WILSOZ (1,4-terephthalylidene-*bis*(*N*-4'-methylaniline))[14] and YAGSEG (*N,N'*-bis(4-methylbenzylidene)benzene-1,4-diamine)[15] (Fig. 2) seems to us to keep the possibility open.

In addition to the role of molecular symmetry, the role of supramolecular synthons[16] in defining molecular packing arrangements can be usefully examined in the context of bridge-flipped isomers. The bridge might be considered a molecular switch, allowing certain synthons to be "switched on" or "switched off" in the solid state, depending on the bridge orientation.[10,17] We are interested in evaluating supramolecular synthons containing fluorine in the context of bridge-flipped isomeric molecules. The role of "organic fluorine," the fluorine atom covalently bonded to carbon, in solid-state molecular packing has been studied extensively in recent years,[2b,18] and the range of viewpoints concerning the ability of fluorine to serve as an acceptor in hydrogen bonding and as a participant in supramolecular synthons involving C-H···F, F···F, and C-F···π contacts has inspired a substantial record in the crystallographic literature and a range of chemical metaphors ranging from "odd man out"[19] to "the little atom that could."[20] Recently Kaur *et al.*[21] have examined an extensive series of fluorine-substituted single-bridge benzylideneanilines and identified the supramolecular synthons involving fluorine in these structures. Among their compounds are four bridge-flipped isomeric pairs, none of which are isomorphous. Collas *et al.*[10] have studied the role of nitrogen position in the bridges of some fluorinated aza-distyrylbenzenes in activating and deactivating fluorine-containing supramolecular synthons; compounds they examined include the *bis*-benzylideneanilines *E,E*-1,4-*bis*[2-(2,3,4,5,6-pentafluorophenyl)-2-azaethenyl]benzene (UKUNUK, Fig. 1) and *E,E-N,N'-bis*(2,3,4,5,6-pentafluorobenzylidene)-1,4-phenylenediamine (UKUPEW, Fig. 1), which also are non-isomorphous.

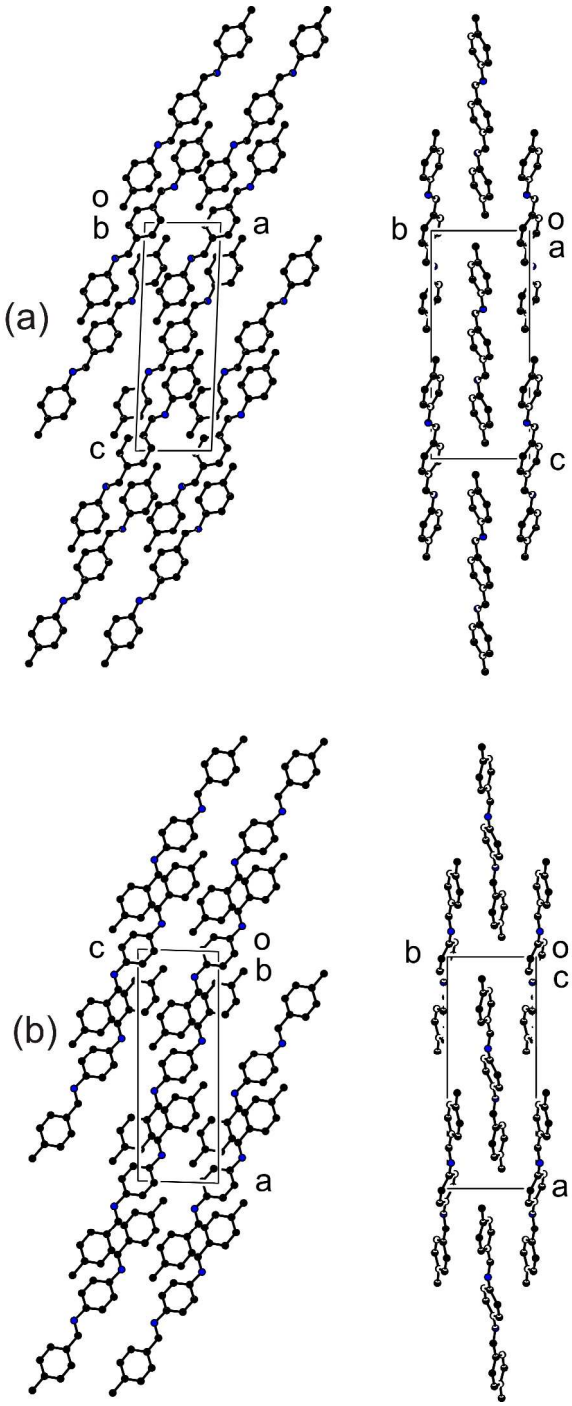

Fig. 2 View of molecular packing in two nearly isomorphous bridge-flipped isomeric *bis*-benzylideneanilines: (a) WILSOZ[14] along [010] (left) and along [100] (right), and (b) YAGSEG[15] (converted from published $P2_1/c$ setting to $P2_1/n$ setting to match WILSOZ) along [010] (left) and along [001] (right). Hydrogen atoms have been omitted for clarity. Cell constants for WILSOZ: a = 6.043(1), b = 7.842(0), c = 18.215(3) Å, β = 92.32(1)°; cell constants for YAGSEG converted to $P2_1/n$: a = 18.69, b = 7.156, c = 6.475 Å, β = 91.73°.

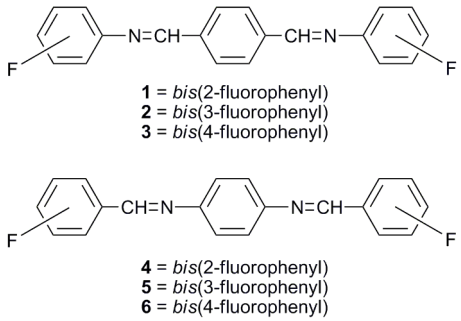

Fig. 3 Bridge-flipped *bis*-benzylideneanilines for which the crystal structures are compared pair-wise in this paper.

In light of these previous studies, we wondered to what extent the fluorine-containing supramolecular synthons observed in simple benzylideneanilines would be preserved in related, fluorine-substituted *bis*-benzylideneanilines, especially where the substitution pattern of a simple fluorobenzylideneaniline would make it essentially a half a molecule of the corresponding *bis*-benzylideneaniline. In connection with our interest in centrosymmetric bridge-flipped isomers, and in spite of the absence of any published examples of isomorphous, fluorine-substituted benzylidenanilines of either the single-bridge or *bis*- type, we also wondered if similar fluorine-containing supramolecular synthons occurring in both members of a bridge-flipped, centrosymmetric *bis*-benzylideneaniline pair might encourage (if not compel) the formation of isomorphous crystals. Both the recurrence of these synthons in *bis*-benzylideneanilines and any tendency toward isomorphism they might encourage would testify to their robustness and to their ultimate usefulness in crystal structure design. Toward addressing these questions, we have determined and describe here the crystal structures of five fluorinated *bis*-benzylideneanilines (Fig. 3): *E,E*-1,4-*bis*[2-(2-fluorophenyl)-2-azaethenyl]benzene, **1**; *E,E*-1,4-*bis*[2-(3-fluorophenyl)-2-azaethenyl]benzene, **2**; *E,E*-1,4-*bis*[2-(4-fluorophenyl)-2-azaethenyl]benzene, **3**; *E,E-N,N'-bis*(2-fluorobenzylidene)-1,4-phenylenediamine, **4**; and *E,E-N,N'-bis*(3-fluorobenzylidene)-1,4-phenylenediamine, **5**. The crystal structure of *E,E-N,N'-bis*(4-fluorobenzylidene)-1,4-phenylenediamine, **6** (HEWHAU) has been described in a recent report by Fang and Cao.[22] In these six crystal structures we identify fluorine-containing motifs that play a role in the molecular packing, and we compare these motifs to those found in the fluorinated *bis*-benzylideneanilines examined by Collas *et al.* and in the fluorinated, single-bridge *N*-benzylideneanilines examined by Kaur *et al*. We hope that through such comparisons we can gain further insight into both the role of organic fluorine in the solid-state packing of molecules in general and the formation (or not) of isomorphous crystal structures by bridge-flipped isomeric molecules in particular.

2 Results and Discussion

Compounds **1**-**5** were prepared and crystallized by standard methods; details of the syntheses, crystallization, and X-ray structure determinations are given in the Experimental section. Cell constants, structure determination details, and refinement parameters

from the single-crystal X-ray analyses are summarized in Table 1. The structure of **2** was found to be disordered to a small (approx. 5%) extent, with the fluorine atom located in either of two positions related by a 180-degree rotation of the fluorophenyl group about the C-N bond. None of the bridge-flipped isomeric pairs in the series **1**-**6** proved to be isomorphous, nor did any pair differing only in the ring position of the fluorine atoms within the terephthaldehyde group **1**-**3** or the phenylenediamine group **4**-**6**, although isomorphism among other compounds differing only in the position of the fluorine substituent on an aromatic ring is known to occur.[2b,21,23] A striking example of an apparent *resistance* to isomorphism is the 4-fluoro substituted pair **3** and **6**. Comparing only their cell constants would suggest at least some structural similarity between these two isomers, given that the two possess closely similar unit cell axis lengths and that both crystallize with four molecules per unit cell in space group $P2_1/c$, but the structure determinations show that the packing arrangements differ entirely. Molecules of **3** assume a non-centrosymmetric conformation (see Section 2.3), and they occupy general positions in the unit cell; the Zorky[24] descriptor is $P2_1/c$, $Z = 4(1)$. In contrast, molecules of **6** assume centrosymmetric conformations and occupy two different crystallographic inversion centers in the unit cell; the Zorky descriptor is $P2_1/c$, $Z = 4(-1^2)$. In our analyses of **1**-**5**, only **3** assumed a non-centrosymmetric conformation and occupied a general position in its cell. Although molecules of **1**, **2**, **4**, **5,** and **6** are located on crystallographic inversion centers, this fact in combination with any conformational and space-filling similarity the bridge-flipped isomers possessed did not result in the formation of isomorphous crystals.

A comparison of the bridge-flipped isomeric pairs **1** and **4**, **2** and **5**, and **3** and **6** with respect to their molecular conformations and their fluorine-containing packing motifs follows here. Selected torsion angles are listed in Table 2; these are consistent with the common observation that in the solid-state structures of benzylideneanilines the aniline ring is twisted farther than the benzylidene ring out of coplanarity with the bridge. Parameters related to the C-H···F, C-H···N, and F···F intermolecular contacts are listed in Table 3. For the purposes of this comparison, a contact less than the sum of the van der Waals radii of H (1.20 Å), N (1.55 Å) or F (1.47 Å) reported by Bondi[25] and used by the *Mercury*[26] program is here considered a "close" contact. Where the standard uncertainty in a contact parameter is not listed, the contact involves a hydrogen atom placed in a calculated position (see Experimental).

2.1 Bridge-flipped isomers *E,E*-1,4-*bis*[2-(2-fluorophenyl)-2-azaethenyl]benzene (1) and *E,E*-*N,N'*-*bis*(2-fluorobenzylidene)-1,4-phenylenediamine (4)

Atom numbering and molecular conformations are shown in Fig. 4(a) for **1** and Fig. 4(b) for **4**. Molecules of **1** are definitely nonplanar with respect to the angle between the fluorophenyl groups and the center ring, and the C-F bond and the bridge C-H bond point in opposite directions. In contrast, molecules of **4** are more nearly planar, and the C-F bond and the bridge C-H bond point in the same direction. These conformational differences between the two isomers are not trends that hold for the remaining isomeric pairs **2**:**5** and **3**:**6**, however (see Sections 2.2 and 2.3), demonstrating that the

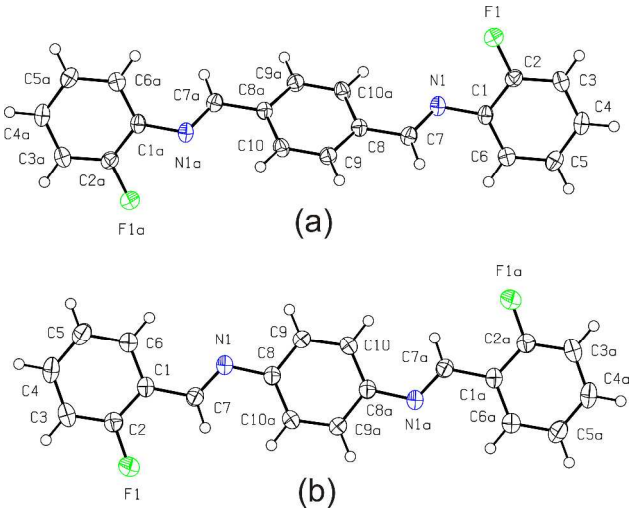

Fig. 4 Anisotropic ellipsoid (50% probability) plots of (a) compound **1** and (b) compound **4**, showing atom numbering.

observed conformations in **1**-**6** depend on intermolecular contacts as well as on intramolecular steric requirements.

In the molecular packing arrangement of **1** (Fig. 5), C-H···F contacts link the molecules into chains extending along [100]. Each of the two bridge H atoms of a given molecule is in contact with a fluorine atom from a different adjacent molecule in the chain: H7(xyz)···F1(-1 + x, y, z) = 2.57 Å. The robustness of this 2-F···bridge-H contact is demonstrated by the existence of a similar contact between a ring fluorine atom in the *ortho*-position and the bridge hydrogen atom in the Kaur *et al.* structures *N*-benzylidene-2-fluoroaniline, 2-fluoro-*N*-(3-fluorobenzylidene)aniline, 2-fluoro-*N*-(4-fluorobenzylidene)aniline, 4-fluoro-*N*-(2-fluorobenzylidene)aniline, 3-fluoro-*N*-(2-fluorobenzylidene)aniline, and the Collas *et al.* structure *E,E*-1,4-*bis*[2-(2,3,4,5,6-pentafluorophenyl)-2-azaethenyl]benzene (UKUNUK). Interestingly, it is absent from both polymorphs of 2-fluoro-*N*-(2-fluorobenzylidene)aniline reported by Kaur *et al*., in which crystallographic disorder exchanges the positions of the bridge CH and N moieties in both structures. In these particular structures any advantage in forming the 2-F···bridge-H supramolecular synthon is insufficient to cause either polymorph to crystallize in an ordered packing arrangement that would allow it.

In contrast to that of **1**, the packing arrangement of **4** (Fig. 6) involves a fluorine-hydrogen close contact in which the hydrogen atom is not the bridge H but is instead one of the H atoms of the central ring: H10(xyz)···F1(1 – x, 1/2 + y, 3/2 – z) = 2.58 Å. The neighboring H atom on the central ring approaches the same fluorine atom at a greater distance: H9(xyz)···F1(1 – x, 1/2 + y, 3/2 – z) = 2.74 Å. The absence of the 2-F···bridge-H synthon and the presence of the 2-F···central ring-H synthon distinguish not only the phenylenediamine derivative **4** from the terephthaldehyde derivative **1** but also the Collas *et al.* phenylenediamine derivative *E,E-N,N'-bis*(2,3,4,5,6-pentafluorobenzylidene)-1,4-phenylenediamine, UKUPEW, from its terephthaldehyde analogue UKUNUK. In both these cases, switching the positions of the nitrogen atoms in the

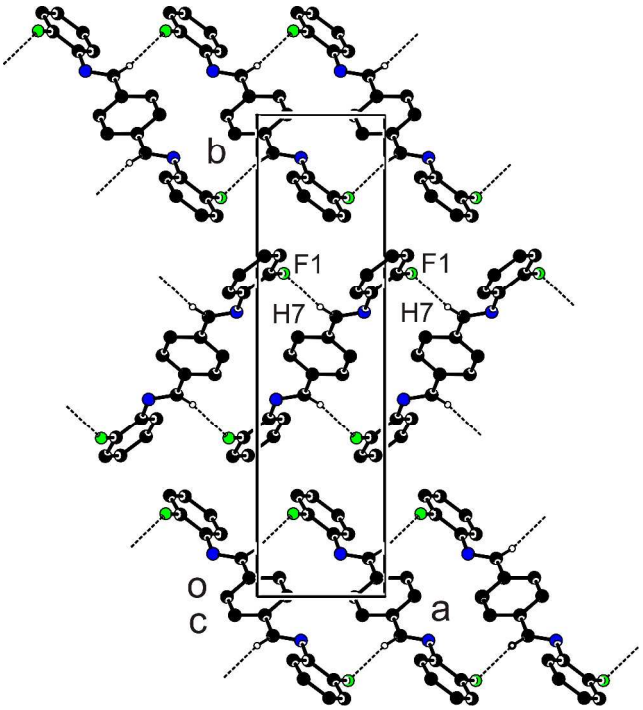

Fig. 5 View along [001] of molecular packing in compound **1** showing 2-F···bridge-H contacts as dashed lines. Hydrogen atoms not involved in these contacts have been omitted for clarity. See Table 3 and text for intermolecular distances and angles.

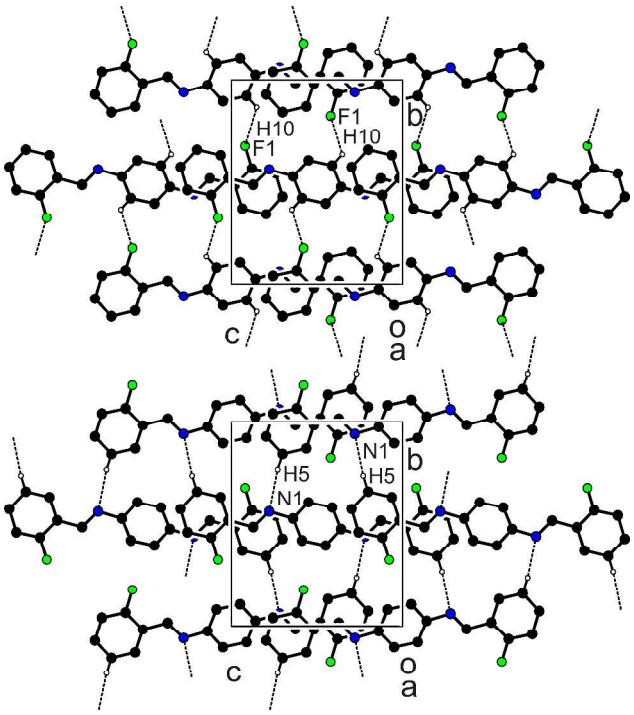

Fig. 6 View along [100] of molecular packing in compound **4** showing close 2-F···ring-H contact (upper) and close ring-H···bridge-N contact (lower) as dashed lines. Hydrogen atoms not involved in these contacts have been omitted for clarity. See Table 3 and text for intermolecular distances and angles.

bridges from a terephthaldehyde core to a phenylenediamine core switches off the 2-F···bridge-H synthon and switches on the 2-F···central ring-H synthon, presumably by increasing the acidity of the central ring H atoms, an effect noted by previous investigators.[10,21] Molecules linked by this latter synthon in **4** are also linked by a contact between a fluorophenyl ring H atom and the bridge N atom: H5(xyz)···N1(x, 3/2 – y, 1/2 + z) = 2.69 Å (Fig. 6). Both the 2-F···bridge-H contact and a fluorophenyl H contact with the bridge N atom were observed in the Kaur *et al.* structure *N*-benzylidene-2-fluoroaniline, a benzylideneaniline that could be considered roughly half a molecule of **1**; unfortunately, a comparison with *N*-(2-fluorobenzylidene)aniline, which could be considered roughly half a molecule of **4**, is not possible because in spite of their efforts, the previous workers were unable to obtain the compound in crystalline form.

2.2 Bridge-flipped isomers *E,E*-1,4-*bis*[2-(3-fluorophenyl)-2-azaethenyl]benzene (2) and *E,E-N,N'-bis*(3-fluorobenzylidene)-1,4-phenylenediamine (5)

Atom numbering and molecular conformations are shown in Fig. 7(a) for **2** (only the major component of the disorder is shown) and in Fig. 7(b) for **5**. As is true of **1** and **4**, the phenylenediamine derivative (**5**) is more nearly planar than the terephthaldehyde derivative (**2**). In direct contrast to **1** and **4**, in **2** the C-F bond and the bridge C-H bond point in the same direction,

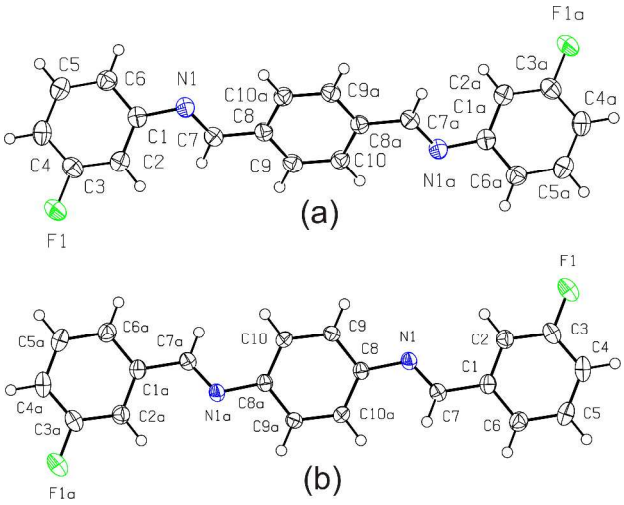

Fig. 7 Anisotropic ellipsoid (50% probability) plots of (a) compound **2** (showing only the major component of the rotational disorder about the C-N bond to the fluorophenyl group) and (b) compound **5**, showing atom numbering.

while in **5** the C-F bond and the bridge C-H bond point in opposite directions. In **2**, the fluorine-containing motif is a 3-F···bridge-H contact, H7(xyz)···F1(1/2 – x, -1/2 + y, 3/2 – z) = 2.52 Å (Fig. 8). In **5**, the fluorine contact is not with the bridge H atom but with an H

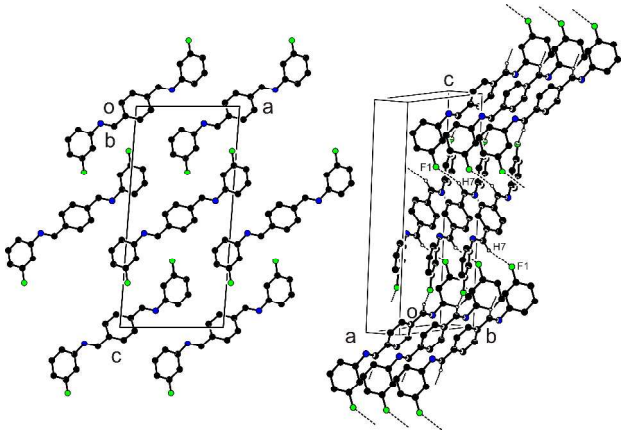

Fig. 8 View of molecular packing in compound **2** along [010] (left) and turned to show 3-F···bridge-H contacts (right). Hydrogen atoms not involved in these contacts have been omitted for clarity. See Table 3 and text for intermolecular distances and angles.

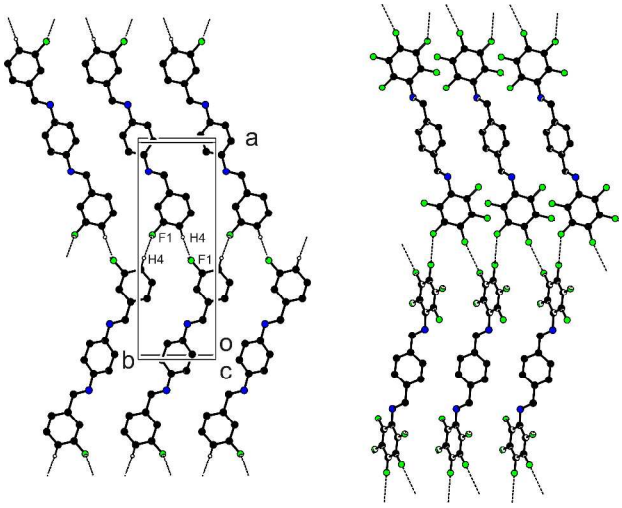

Fig. 9 View of molecular packing in (left) compound **5** approximately along [001] and perpendicular to a sheet of molecules linked by 3-F···4-H contacts, and in (right) UKUNUK, showing 3-F···4-F contacts analogous to the 3-F···4-H contacts in **5**. Hydrogen atoms not involved in these contacts have been omitted for clarity. See Table 3 and text for intermolecular distances and angles.

atom *ortho* to the F atom on the fluorophenyl ring, *para*-hydrogen H(4)(xyz)···F1(1 – x, -1/2 + y, 1/2 – z) = 2.59 Å, a contact that links molecules of **5** into extended sheets (Fig. 9). Neither of these fluorine-based motifs is observed in the other *meta*-fluoro substituted benzylideneanilines 3-fluoro-*N*-(4-fluorobenzylidene)aniline, 4-fluoro-*N*-(3-fluorobenzylidene)aniline, 3-fluoro-*N*-(3-fluorobenzylidene)aniline, 2-fluoro-*N*-(3-fluorobenzylidene)aniline, 3-fluoro-*N*-(2-fluorobenzylidene)aniline, or *N*-benzylidene-3-fluoroaniline (which could be considered roughly half a molecule of **2**) examined by Kaur *et al.* Where a 3-F···4-H synthon appears in these structures, it is part of an $R^2_2(8)$ interaction that defines dimers instead of chains. Comparison with *N*-(3-fluorobenzylidene)aniline (which could be considered roughly half a molecule of **5**) is not possible because the compound could not be obtained in crystalline form. On the other hand, a topological similarity between the 3-F···4-H based motif in **5** and a corresponding F···F motif in the Collas *et al.* structure UKUNUK can be identified if the role of the 4-H atom on the fluorophenyl ring of **5** is played by the 4-F atom in UKUNUK (Fig. 9). This kind of motif is not found in UKUPEW, even though both **5** and UKUPEW possess the phenylenediamine core while UKUNUK possesses the terephthaldehyde core. It is possible to form an interaction topologically similar to the 3-F···4-H motif in **5** by exchanging the positions of the F and H atoms on the ring. This interaction thus should be possible for *para*-fluorinated derivatives and is in fact found in the Kaur *et al.* structure 4-fluoro-*N*-(4-fluorobenzylidene)aniline; however, it is not found in the *para*-fluorinated compounds **3** and **6** (Section 2.3).

2.3 Bridge-flipped isomers *E,E*-1,4-*bis*[2-(4-fluorophenyl)-2-azaethenyl]benzene (3) and *E,E*-*N,N'*-*bis*(4-fluorobenzylidene)-1,4-phenylenediamine (HEWHAU) (6)

The atom numbering and molecular conformation of **3** are shown in Fig. 10(a). For comparison, the atom numbering and conformations of the two molecules located on two different

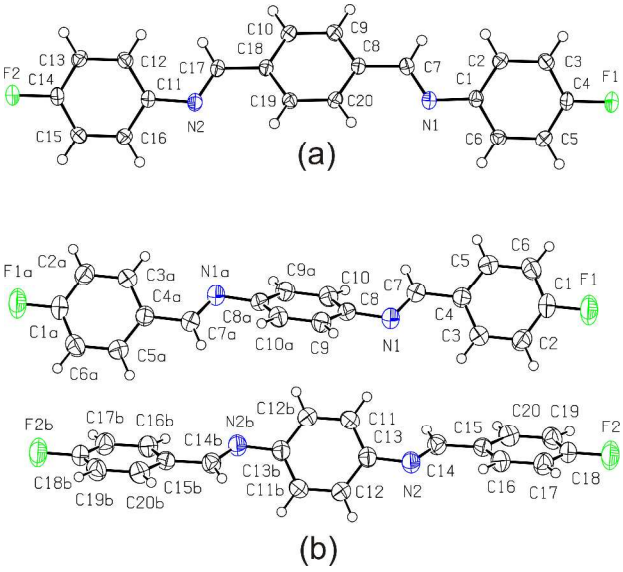

Fig. 10 Anisotropic ellipsoid (50% probability) plots of (a) compound **3** and (b) two crystallographically independent molecules of compound **6,** HEWHAU, showing atom numbering.

inversion centers in the unit cell of HEWHAU,[22] compound **6,** are shown in Fig. 10(b). Unlike the previous bridge-flipped pairs, molecules of **3** and **6** are similar in the extent to which they deviate from planarity, with angles calculated using *Mercury* between the least-squares planes of the center ring and the fluorophenyl rings in the two isomers varying over a range of slightly less than three degrees (from 51.42° to 54.33°). As noted above, molecules of **3** and **6** do differ significantly in conformation with respect to the

bridges, with molecules of **3** occupying general positions in the unit cell and molecules of **6** occupying inversion centers. A C-H···N close contact is found in **3**: H(12)(xyz)···N1(1 – x, 1/2 + y, 1/2 – z) = 2.70 Å. Compounds **3** and **4** are the only ones in the **1**-**6** series in which a close contact exists between a C-H hydrogen atom and a bridge nitrogen atom; the relative positions occupied by these nitrogen atoms in the bridge, differing in terephthaldehyde derivative **3** and phenylenediamine derivative **4**, thus appear to have little bearing on whether or not C-H contacts to these N atoms can be made.

Isomers **3** and **6**, although different in overall crystal structure, possess strikingly similar intermolecular packing motifs involving the fluorine atom if the intermolecular approaches under consideration are allowed to extend by 0.10 Å beyond the sum of the van der Waals radii.[26] In **3** (Fig. 11(a)), both fluorine atoms are simultaneously part of two five-membered-ring, pincer-type interactions. The C4-F1 and C5-H5 bonds of a given molecule are directed toward F2 of a neighboring glide-related molecule: F1(xyz)···F2(-1 + x, 1/2 – y, -1/2 + z) = 2.9786(13) Å; H5(xyz)···F2(-1 + x, 1/2 – y, -1/2 + z) = 2.67 Å, while F1 is also approached by the C14-F2 and C13-H13 bonds of a second glide-related molecule: F1(xyz)···F2(-1 + x, 3/2 – y, -1/2 + z) = 2.9654(13) A; F1(xyz)···H13(-1 + x, 3/2 – y, -1/2 + z) = 2.67 Å. In **6** (Fig. 11(b) and Fig. 11(c)), the two independent molecules both engage in fluorine-containing pincer-type interactions similar to those found in **3** but differing in the symmetry involved (glide symmetry for **3**, screw-axial symmetry for **6**). For one of these molecules, the C1-F1 and C2-H2 bonds are directed toward F1 of a neighboring molecule: F1(xyz)···F1(1 – x, -1/2 + y, 3/2 – z) = 3.0253(16) Å; H2(xyz)···F1(1 – x, -1/2 + y, 3/2 – z) = 2.68 Å, while F1 is approached by the C1-F1 and C2-H2 bonds of a second neighboring molecule: F1(xyz)···F1(1 – x, 1/2 + y, 3/2 – z) = 3.0253(16) Å; F1(xyz)···H2(1 – x, 1/2 + y, 3/2 – z) = 2.68 Å. For the other independent molecule, the C18-F2 and C19-H19 bonds are directed toward F2 of a neighboring molecule: F2(xyz)···F2(-x, 1/2 + y, 3/2 – z) = 3.0343(16) Å; H19(xyz)···F2(-x, 1/2 + y, 3/2 – z) = 2.76 Å, while F2 is approached by the C18-F2 and C19-H19 bonds of a second neighboring molecule: F2(xyz)···F2(-x, -1/2 + y, 3/2 – z) = 3.0343(16) Å; F2(xyz)···H19(-x, -1/2 + y, 3/2 – z) = 2.76 Å.

This dual-pincers motif is also found in the similarly *bis*-*para*-fluorinated compound 4-fluoro-*N*-(4-fluorobenzylidene)aniline, but it is not found in the other *para*-fluoro substituted compounds 3-fluoro-*N*-(4-fluorobenzylideneaniline), 2-fluoro-*N*-(4-fluorobenzylidene)aniline, 4-fluoro-*N*-(3-fluorobenzylidene)aniline, 4-fluoro-*N*-(2-fluorobenzylidene)aniline, *N*-benzylidene-4-fluoroaniline (approximately half a molecule of **3**), or *N*-(4-fluorobenzylidene)aniline (approximately half a molecule of **6**) examined by Kaur *et al.* No analogous motif is apparent in the Collas *et al.* structures UKUNUK and UKUPEW.

3 Experimental

Compounds **1**-**5** were prepared using a standard method, condensation of one equivalent of the "core" compound (for **1**-**3**, terephthaldehyde; for **4** and **5**, phenylenediamine) with two

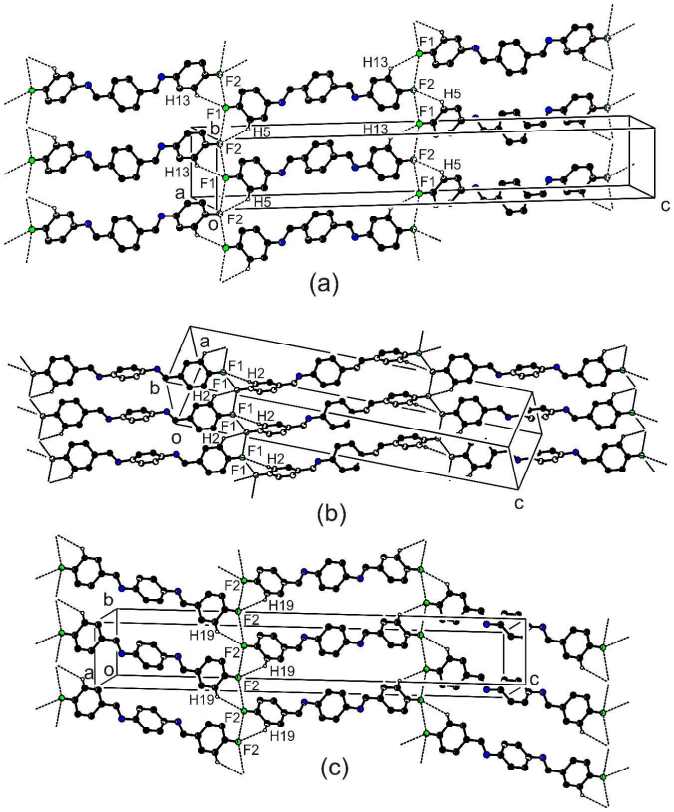

Fig. 11 Views of dual-pincer intermolecular approaches in (a) compound **3** and in (b), (c) compound **6**, HEWHAU. Hydrogen atoms not involved in these contacts have been omitted for clarity. See Table 3 and text for intermolecular distances and angles.

equivalents of the corresponding fluoroaniline derivative (for **1**-**3**) or fluorobenzaldehyde derivative (for **4** and **5**) by warming the reaction mixture for 15-30 minutes in ethanol solution. Crystals were obtained either by slow cooling of the ethanolic reaction mixture or by recrystallization of the crude solid from ethanol (for **1**, **2**, **3**, and **5**) or from 1:1 methanol:chloroform (for **4**). For single-crystal X-ray studies, compound **1** was obtained as yellow needles, mp 421-422 K; compound **2** was obtained as yellow blocks, mp 395-396 K; compound **3** was obtained as colorless plates, mp 423-424 K; compound **4** was obtained as yellow plates, mp 390-391 K, and compound **5** was obtained as yellow needles, mp 401-403 K. Data sets were collected at 173 K using MoKα radiation (λ = 0.71073 Å) and *SMART*[27] (for **1**) or *APEXII*[28] (for **2**-**5**) software on a Siemens (for **1**) or Bruker (for **2**-**5**) CCD diffractometer. Data reduction was accomplished using *SAINT*[27] (for **1**) or *APEX2*[28] (for **2**-**5**). Absorption corrections were applied to **1**-**5** using *SADABS*.[27] Structure solution and refinement were performed using *SHELXTL*.[29] All non-hydrogen atoms were refined anisotropically; all hydrogen atoms were placed in calculated positions (riding model). As noted previously, a low-intensity residual peak in the difference map of **2** indicated disorder in the position of the fluorine atom corresponding to a 180-degree rotation of the 3-fluorophenyl group about the C-N bond. Modeling this disorder by assigning two positions for the

fluorine atom while applying the restraint of equal anisotropic displacement parameters for the two fluorine sites resulted in component percentages after refinement of 95% and 5%. Analysis and plotting of the structures were performed using *PLATON*[30] and *Mercury*.

CCDC 974614-974618 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

4 Conclusion

Our examination of **1**-**6** has not provided any new examples of isomorphous bridge-flipped isomers. Instead, it has demonstrated that structural features such as molecular conformation and intermolecular contacts that must be closely similar in order for bridge-flipped isomeric pairs to assume the same molecular packing arrangement actually display wide variability in these *bis*-benzylideneanilines. Their conformational flexibility ensures that even when a centrosymmetric conformation is possible for these molecules, no guarantee exists that both isomers will assume it. The occurrence of fluorine-based supramolecular synthons in the molecular packing is undoubtedly significant with respect to how the molecules of individual *bis*-benzylideneanilines self-assemble, but the influence of these synthons apparently does not extend to compelling isomorphism between bridge-flipped isomeric *bis*-benzylideneanilines. Although we have found one particular fluorine-containing supramolecular synthon, the 2-F···bridge-H contact, to be sufficiently robust to occur in a variety of benzylideneanilines of both the single-bridge and *bis*- type, it is not sufficiently robust to occur in both of the 2-fluorinated bridge-flipped *bis*-benzylideneanilines **1** and **4** and contribute to their isomorphism. At the same time, the fact that its occurrence is not specific to only one bridge orientation (2-fluoroaniline vs. 2-fluorobenzylidene)—*i.e*. to one position of the "synthon switch"—may limit its usefulness to some extent as a reliable supramolecular synthon in future crystal engineering applications. In the one instance in the **1**-**6** series, namely **3** and **6**, in which a pair of bridge-flipped isomeric benzylideneanilines do engage in similar fluorine-implicated intermolecular interactions, these interactions are insufficient to cause the two isomers to assume the same packing arrangement. The occurrence of particular fluorine-containing supramolecular synthons in the crystal structures of those single-bridge benzylideneanilines that can be considered "half-molecules" of analogous *bis*-benzylideneanilines has proved in our examples not to be a reliable predictor of which fluorine-containing supramolecular synthons will occur in the related *bis*-benzylideneaniline. Ultimately, it appears that flexibility in assuming a variety of molecular conformations and capability of engaging in a variety of fluorine-containing supramolecular synthons, both factors that might facilitate isomorphism, instead have been used by the *bis*-benzylideneanilines in our study to avoid it.

Acknowledgements

Support of this work by the National Science Foundation through grant DMR05-20415 administered by the Materials Research Facilities Network (MRFN) is gratefully acknowledged. Acknowledgement for their support is also made to the donors of the American Chemical Society Petroleum Research Fund and to the University of St. Thomas Department of Chemistry. The authors thank Dr. Victor G. Young, Jr. (Director) of the X-ray Crystallographic Laboratory of the University of Minnesota Department of Chemistry for his assistance and Dr. Doyle Britton (Department of Chemistry) and Dr. William B. Gleason (Department of Laboratory Medicine and Pathology) of the University of Minnesota for helpful discussions.

Notes and References

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Table 1 Details of data collection and structure refinement for **1-5**

Compound reference	**1**	**2**	**3**	**4**	**5**
Chemical formula	$C_{20}H_{14}N_2F_2$	$C_{20}H_{14}N_2F_2$	$C_{20}H_{14}N_2F_2$	$C_{20}H_{14}N_2F_2$	$C_{20}H_{14}N_2F_2$
Formula mass	320.33	320.33	320.33	320.33	320.33
Crystal system	monoclinic	monoclinic	monoclinic	monoclinic	monoclinic
Space group	$P2_1/n$	$P2_1/n$	$P2_1/c$	$P2_1/c$	$P2_1/c$
a/Å	5.8090(7)	9.4317(14)	7.4680(11)	6.9517(6)	17.2826(17)
b/Å	20.942(3)	3.9520(6)	5.6986(8)	11.5713(10)	6.1796(6)
c/Å	6.6746(8)	20.303(3)	36.149(5)	10.0545(8)	7.0765(7)
α/°	90	90	90	90	90
β/°	107.509(2)	94.204(2)	95.239(2)	104.6180(10)	92.710(1)
γ/°	90	90	90	90	90
Unit cell volume/Å^3	774.35(16)	754.7(2)	1532.0(4)	782.61(11)	754.92(13)
Z (formula units/cell)	2	2	4	2	2
Temperature/K	173(2)	173(2)	173(2)	173(2)	173(2)
Radiation type	MoKα	MoKα	MoKα	MoKα	MoKα
Abs. coeff., μ/mm^{-1}	0.098	0.101	0.099	0.097	0.101
No. of refl. measured	8930	8607	17753	8953	4277
No. of indep. refl.	1781	1697	3550	1785	1692
R_{int}	0.0333	0.0255	0.0253	0.0387	0.0165
Final R_1 ($I>2\sigma(I)$)	0.0389	0.0539	0.0411	0.0387	0.0379
Fnl. $wR(F^2)$ ($I>2\sigma(I)$)	0.0876	0.1382	0.1154	0.0925	0.1027
Final R_1 (all data)	0.0591	0.0611	0.0540	0.0498	0.0453
Fnl. $wR(F^2)$ (all data)	0.0951	0.1416	0.1243	0.0994	0.1092
Goodness of Fit on F^2	1.047	1.139	1.055	1.074	1.050
CCDC number	974614	974615	974616	974617	974618

Table 2. Selected torsion angles (°). Corresponding angles with different atom labels are indicated by superscripts.

	C6-C1-N1-C7	N1-C7-C8-C10(a)
1	43.78(19)	11.14(19)
2	-142.0(2)	5.2(3)
3	-145.21(12)	13.00(19)[a]
	143.11(12)[b]	-13.60(19)[c]

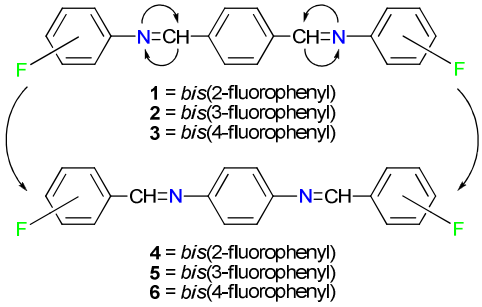
	C6-C1-C7-N1	C7-N1-C8-C10(a)
4	6.2(2)	-20.1(2)
5	-164.02(12)	-29.79(18)
6	12.1(2)[d]	39.9(2)[e]
	-14.2(2)[f]	-39.3(2)[g]

[a]N1-C7-C8-C20 [b]C16-C11-N2-C17 [c]N2-C17-C18-C19 [d]C3-C4-C7-N1 [e]C7-N1-C8-C10 [f]N2-C14-C15-C16 [g]C14-N2-C13-C11

Table 3. Selected intermolecular D-X···A contacts in **1**-**6** (D-X at xyz)

	D	X	A	X···A/Å	D-X···A/°	Symmetry code of A
1	C7	H7	F1	2.57	170	-1 + x, y, z
2	C7	H7	F1	2.52	156	1/2 – x, -1/2 + y, 3/2 – z
3	C5	H5	F2	2.67	130	-1 + x, 1/2 – y, -1/2 + z
	C4	F1	F2	2.9786(13)	106.11(7)	-1 + x, 1/2 – y, -1/2 + z
	C4	F1	F2	2.9654(13)	104.74(7)	-1 + x, 3/2 – y, -1/2 + z
	C4	F1	H13	2.67	149	-1 + x, 3/2 – y, -1/2 + z
	C12	H12	N1	2.70	141	1 – x, 1/2 + y, 1/2 – z
4	C2	F1	H9	2.74	132	1 – x, -1/2 + y, 3/2 – z
	C9	H9	F1	2.74	120	1 – x, 1/2 + y, 3/2 – z
	C2	F1	H10	2.58	131	1 – x, -1/2 + y, 3/2 – z
	C10	H10	F1	2.58	127	1 – x, 1/2 + y, 3/2 – z
	C5	H5	N1	2.69	162	x, 3/2 – y, 1/2 + z
5	C4	H4	F1	2.59	149	1 – x, -1/2 + y, 1/2 – z
	C3	F1	H4	2.59	128	1 – x, 1/2 + y, 1/2 – z
6	C1	F1	F1	3.0253(16)	106.35(10)	1 – x, -1/2 + y, 3/2 – z
	C2	H2	F1	2.68	133	1 – x, -1/2 + y, 3/2 – z
	C1	F1	F1	3.0253(16)	107.80(10)	1 – x, 1/2 + y, 3/2 – z
	C1	F1	H2	2.68	154	1 – x, 1/2 + y, 3/2 – z
	C18	F2	F2	3.0343(16)	108.90(10)	-x, 1/2 + y, 3/2 – z
	C19	H19	F2	2.76	134	-x, 1/2 + y, 3/2 – z
	C18	F2	F2	3.0343(16)	104.34(10)	-x, -1/2 + y, 3/2 – z

C18	F2	H19	2.76	152	-x, -1/2 + y, 3/2 – z



The non-isomorphous crystal structures of "bridge-flipped" isomers **1**-**5** are described and are compared to those of previously published **6** and to those of a series of recently reported fluorinated benzylideneanilines.