Preparations, Crystal Structures, and Unusual Proton NMR Characteristics of Some Phthalimides

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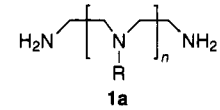
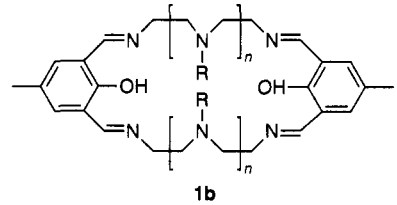
Protection of NH_2 groups as phthalimides using a mixture of acetic acid, phthalic anhydride, and the relevant polyamine can take unusual routes. For diethylenetriamine the major product is diphthalimidodiethylammonium–hydrogen phthalate (**DPDAH–HP**). For triethylenetetraamine, ethylene migration products *N,N*-bis(2-phthalimidoethyl)piperazine (**2**) and *N,N′,N″*-(nitrilotriethylene)trisphthalimide (**3**) were obtained from room temperature and refluxing reaction mixtures, respectively. The crystal structures of **2**, **3**, and **DPDAH–HP** were determined and reveal a series of stabilizing complementary interactions for these favored products (i.e., offset $\pi-\pi$ stacking and C–H···O and possibly C–H···N hydrogen bonds (**2**), electrostatic interactions between the amine and pyrrolic functionalities (**3**), and offset $\pi-\pi$ stacking and N–H···O hydrogen bonding (**DPDAH–HP**)). The **DPDAH–HP** units stack along a screw axis parallel to the *b*-direction to yield a striking [phthalimide–phthalimide–hydrogen phthalate]$_n$ motif and are linked in the *a* and *c* directions by N–H···O bonds. Solution ^{1}H NMR studies of **3** reveal unusual temperature (178–420 K) evolution of sharp aromatic proton resonances in various solvents. Typically, the spectra exhibit a spectacular temperature evolution from a sharp doublet of quartets at high temperature to complex second-order behavior and then a singlet. As the temperature is further lowered, a complex second order spectrum reappears followed by a doublet of quartets. The phthalimide–amine interaction energy, determined from temperature dependent NMR studies, is *ca.* 20 kJ/mol. Solid state ^{13}C aromatic resonances are broadened by $\pi-\pi$ interactions in **2** and **DPDAH–HP** while two sets of ^{13}C resonances are found for **3** as expected from the solid state structures. The hydrogen phthalate anion in **DPDAH–HP** exchanges rapidly with free phthalic acid (equilibrium constant, $K \simeq 4 \times 10^2$ L/mol); this phthalate exchange exhibits almost temperature independent behavior indicating that it is predominantly entropy driven.

Introduction

Poor solubility and kinetic and thermodynamic instability are major problems which must be overcome before the interesting polynucleating coordination cavities exhibited by a plethora of Schiff base chelates[1–4] can find applications in catalysis[5] or biomedical diagnostics.[6,7] Those problems may be solved by reduction of Schiff base iminic sites and subsequent introduction of good metal ion binding carboxylate, alkoxide, or phosphonate functionalities into the resulting NH sites. This approach has worked so well for pyridine tetraazamacrocycles,[8] tetraazacyclododecane (cyclen)[9] and 1,4,8,11-tetraazatetradecane (cyclam),[6] that some of their derivatives are currently in routine *in vivo* clinical use.[10] Alternatively, the good metal ion binding functionalities can be built into Schiff base precursors, such as **1a**, prior to the condensation stage.



1a



1b

$(n = 1, 2)$

R = H, CH_2COOH, CH_2CH_2OH, $CH_2CH_2PO_3H_2$

This route is attractive in view of the extreme instability of potentially useful polynucleating chelates such as **1b** (n = 2, R = H) which are stabilized by metal ions.[11] Because of the interesting electronic properties exhibited by dinuclear rare earth Schiff base complexes[3,12] we

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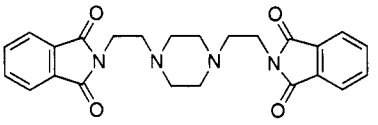
sought to extend our studies to potentially novel water soluble and stable Schiff base complexes derived from precursors such as **1a**.

Selective functionalization of the secondary amine **1a** (R = H) to produce **1a** (R ≠ H) requires prior protection of the primary amine sites. We sought to accomplish this selective protection using a literature procedure which employs a refluxing mixture of acetic acid, phthalic anhydride, and the relevant polyamine, henceforth the acetic acid–phthalic anhydride–polyamine protocol (A–P–P), which is claimed to work well for **1a** (R = H, n = 1).[13,14] However, we find the A–P–P to be more complicated, producing diphthalimidodiethylammonium-hydrogen phthalate (**DPDAH–HP**) for **1a** (R = H, n = 1); **2** and **3** are preferred for **1a** (R = H, n = 2).



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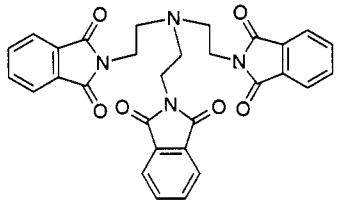

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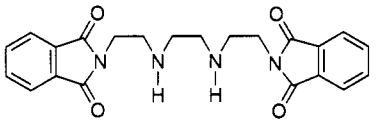

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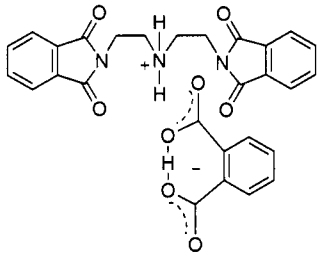

DPDAH–HP

We have studied in detail the structural and NMR characteristics of these products in order to establish conclusively their identity and formation as well as determine the mitigating factors favoring the reaction routes in which they are formed.

Herein we report the preparation, crystal structures, and NMR characteristics of **2**, **3**, and **DPDAH–HP** which show these preferred A–P–P products to be stabilized by noncovalent interactions such as π–π stacking and H-bonding and reveal unusual temperature evolution of phthalimide aromatic ^{1}H resonances.

Results and Discussion

Syntheses and Molecular Structure. The formation of ethylene migration products **2** and **3** in the A–P–P with **1a** (R = H, n = 2) is preferred to the desired linear diphthalimide **4**. The formation of these compounds was revealed by elemental, NMR,[15] IR, and mass spectrometric analyses, but the most convincing evidence comes from the single crystal X-ray crystallographic study. The molecular structures of **2** and **3** are given in Figures 1 and 2 and show that the A–P–P modifies the **1a** (R = H, n = 2) framework to yield the branched ethylene migration products. For the products from **1a** (R = H, n = 1), elemental analyses, a complicated IR spectrum, and ^{1}H NMR clearly indicate that the product of the A–P–P is not the desired diphthalimidodiethylamine (**DPDA**).[13,14] Single crystal X-ray crystallography analysis proves the formation of a novel **DPDAH–HP** complex (Figure 3), stabilized by complementary π–π

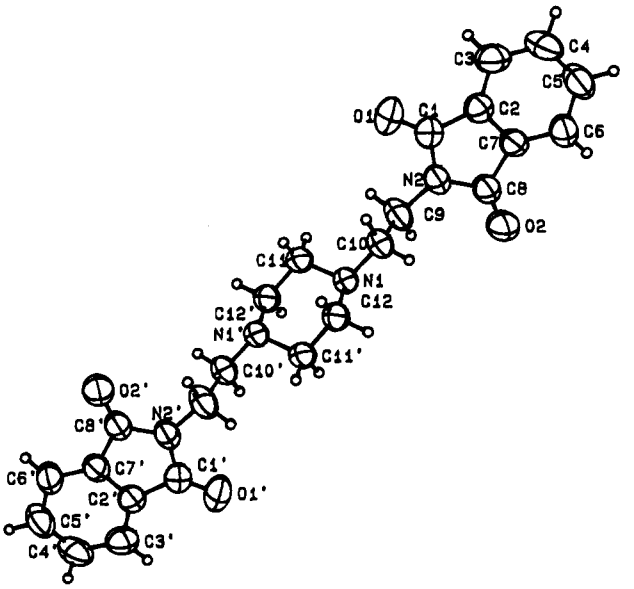

Figure 1. Molecular structure of **2**, the product of the A–P–P with **1a** (R = H, n = 2) at room temperature.

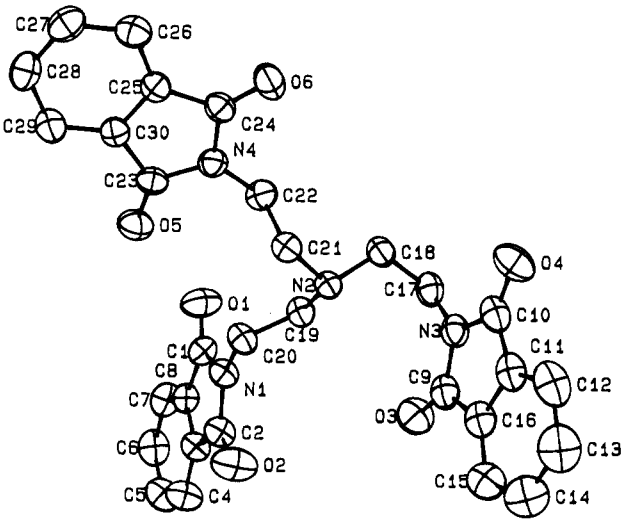

Figure 2. Molecular structure of **3**, the product of the A–P–P with **1a** (R = H, n = 2) (refluxing conditions) showing the n-pyrrolic interaction (phthalimide built on N(3)).

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(15) NMR data (200 MHz; $CDCl_3$; δ ppm). For **2**: ^{1}H 2.52 (singlet), 2.59 (triplet), 3.78 (triplet), 7.70 (multiplet), 7.82 (multiplet); ^{13}C 35.28, 53.01, 55.64, 123.15, 132.22, 133.80, 168.32. For **3**: ^{1}H 2.90 (triplet), 3.74 (triplet), 7.69 (singlet); ^{13}C 35.35, 51.53, 52.95, 123.02, 132.18, 133.82, 168.15. For **DPDAH–HP** in $(CD_3)_2SO$: ^{1}H 3.19 (triplet), 3.81 (triplet, 7.47 (quartet), 7.85 (multiplet), 8.03 (quartet).

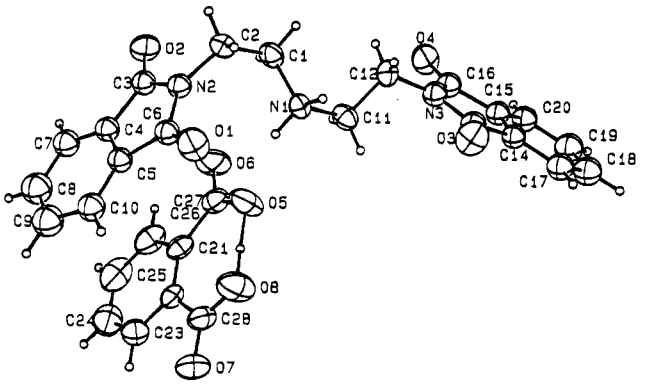

Figure 3. Structure of the asymmetric unit of **DPDAH–HP** showing interacting phthalimide and hydrogen phthalate species.

stacking, carbonyl–carbonyl, and X–H···O (X = N, O) hydrogen bonding interactions. This product is also obtained when phthalic acid reacts directly with **DPDA** or when **DPDA** is hydrolyzed under acidic conditions. Earlier literature reports[13,14] do not give the properties of the A–P–P/**1a** (R = H, n = 1) products, which were subsequently used under basic conditions to prepare compounds with N-R functionalities. Our studies show that **DPDAH–HP** decomposes to **DPDA** and phthalate anions under these basic conditions.

Ethylene migration processes in alkylamines are known,[16] but they are of low yield and demand high pressure and temperatures as well as catalysts. By contrast, the A–P–P gives high yields of ethylene migration products under relatively mild reaction condition. Whereas a modified version of the A–P–P (*vide supra*) works for **1a** (R = H, n = 1), protection of higher polyamines **1a** (R = H, n > 1) cannot be accomplished by this method. Since the nature of the phthalimide product isolated from the A–P–P critically depends on the experimental conditions and the identity of the polyamine, we have studied the crystal structures of **2**, **3**, and **DPDAH–HP** in more detail to determine the stabilizing interactions which contribute to these favorable reaction routes.

Solid-State Structures. The molecule of **2** has crystallographically imposed $\bar{1}$ symmetry with the piperazine ring adopting the chair conformation. The molecule is in the "fully extended" conformation (Figure 1) which permits efficient packing within the crystal. There are weak intermolecular interactions consisting of offset π–π stacking interactions[17–19] and hydrogen bonds.[20–22] The former are shown in Figure 4 and involve C- - -C contracts of 3.769(2) Å (C(2)- - -C(6′), 3.472(3) Å (C(5)- - -C(7)′), 3.625(3) Å (C(5)- - -C(8)′), 3.624(4) Å (C(6)- - -C(6)′), and 3.637(2) Å (C(6)- - -C(7)′). Such distances are typical of π–π stacking,[19] and the offset nature of the stacking is consistent with rules developed recently by Hunter and Sanders[17,19] which indicate π–σ interactions to be dominant (rule 3). Weak O- - -H–C hydrogen bonds[20–22] are indicated by the contacts O(1)- - -H(7′) = 2.51(2) Å and O(2)- - -H(2″) = 2.83(2) Å and by the angles O(1)- - -H(7′)–C(10′) = 176° and O(2)- - -H(1″)–C(3″) = 171° where the primed and double primed atoms are related to those in the asymmetric unit by the transformations $x, y, -1 + z$ and $1 + x, y, 1 + z$, respectively. The O(1)- - -C(10′) and O(2)- - -C(3″) separations are, respectively, 3.50 and 3.73 Å. In addition, the N(1)- - -H(1″) contact of 2.76(2) Å suggests the possibility of a weak N- - -H–C hydrogen bond, but as the N(1)- - -H(1″)–C(4″) angle is 150°, this conclusion is less certain.

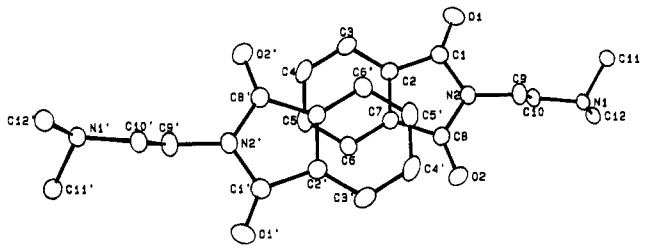

Figure 4. Offset π–π stacking between molecules of **2**. The primed atoms are related to the unprimed atoms by a center of symmetry at ($^1/_2$, $^1/_2$, $^1/_2$).

Figure 2 gives a perspective view of **3** from which it is evident that two of the phthalimidoethyl substituents are "fully extended" while the third, that built on N(3), is folded back over N(2). This is supported by the torsion angles involving these three substituents, viz. N(2)–C(19)–C(20)–N(1) = −168.2(2)°, N(2)–C(21)–C(22)–N(4) = 171.8(2)°, N(2)–C(18)–C(17)–N(3) = −61.7(3)°. Since there do not appear to be any unusual intermolecular contacts involving the "folded back" phthalimidoethyl group, we conclude that the conformation observed in the crystal results from an attractive interaction between the atoms of the pyrrolic moiety containing N(3) and the lone pair on the amine nitrogen (N(2)). This conclusion is supported by the short, noncovalent contacts N(2)- - -N(3) (3.02 Å), N(2)- - -C(9) (3.54 Å), and N(2)- - -C(10) (3.88 Å). The sum of bond angles about the imide nitrogens, 359.7° (N(1)), 359.9° (N(3)), and 359.9° (N(4)), is consistent with planarity and the presence of some positive charge associated with the phthalimide functionality.[23–24] The interaction of N(2) with N(3), C(9), and C(10) appears to be predominantly electrostatic. Studies of the electronic characteristics of some N-(aminoalkyl)phthalimides have frequently invoked the significance of imide–amino interactions for understanding cooperative phenomena in the photophysics and

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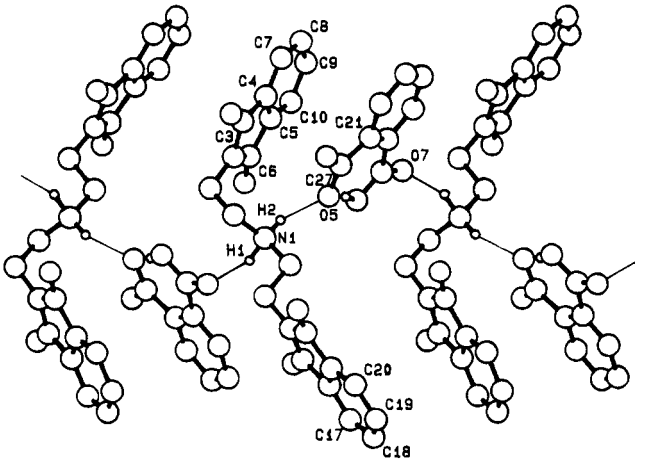


Figure 5. Supramolecular [phthalimide–phthalimide–hydrogen phthalate]$_n$ stacks showing the intermolecular hydrogen bonding.

photochemistry of phthalimide systems.[25] To the best of our knowledge, this is the first structural demonstration of these interactions.

Figure 3 shows a perspective view of the asymmetric unit of the **DPDAH–HP** complex while Figure 5 shows the association of these units along the 2_1 axis. This supramolecular ribbon, based on the [phthalimide–phthalimide–hydrogen phthalate] stack as the repeating unit, is stabilized by complementary hydrogen bonding, offset $\pi-\pi$ stacking, and electrostatic interactions. The hydrogen bonding is shown in Figure 5 and consists of the H(2)- - -O(5) interaction 1.92(5) Å) within the **DPDAH–HP** unit and an O(7)- - -H(1)′ interaction (1.73(7) Å) connecting adjacent units. Figure 6a illustrates the offset $\pi-\pi$ phthalimide–hydrogen phthalate stacking within the **DPDAH–HP** unit which is characterized by the C- - -C contacts C(3)- - -C(27) = 3.593(6), C(5)- - -C(21) = 3.538(6), C(5)- - -C(27) = 3.280(6), C(6)- - -C(27) = 3.413(6), and C(10)- - -C(21) = 3.541(6) Å. The short intramolecular O(5)···C(6) and O(6)···C(3) distances, 3.087(6) and 3.098(6) Å, respectively, are indicative of carbonyl···carbonyl interactions in the **DPDAH–HP** unit. The mean planes of the two aromatic moieties are *ca.* 8.1(5)° from coplanarity. Figure 6b shows the offset $\pi-\pi$ stacking of adjacent phthalimide units. Pertinent C- - -C contacts are C(3)- - -C(17)′ = 3.393(6), C(3)- - -C(18)′ = 3.440(7), C(4)- - -C(18)′ = 3.297(7), C(4)- - -C(19)′ = 3.519(7), C(5)- - -C(19)′ = 3.424(7), and C(6)- - -C(20)′ = 3.592(2) Å. The two sets of $\pi-\pi$ stacking interactions are thus of comparable magnitude, and their offset nature is again consistent with rule 3 of Hunter and Sanders,[17,19] indicating the dominance of $\pi-\sigma$ interactions. That **DPDAH–HP** is correctly formulated as an ion pair (i.e., protonation of N(1) by phthalic acid), rather than as a cocrystallized mixture of phthalic acid and the secondary amine, is established by the observation that the *refined* N(1)–H distances (N(1)–H(1) = 1.06(7), N(1)–H(2) = 0.91(5) Å) are equal within experimental error as expected for a quaternized nitrogen. Further, these distances are much shorter than the distances to the oxygen atoms with which the hydrogens are also associated (H(1)- - -O(7)′ = 1.73(7), H(2)- - -O(5) = 1.92(5) Å). In this compound as well as in **2** and **3**, all the intramolecular

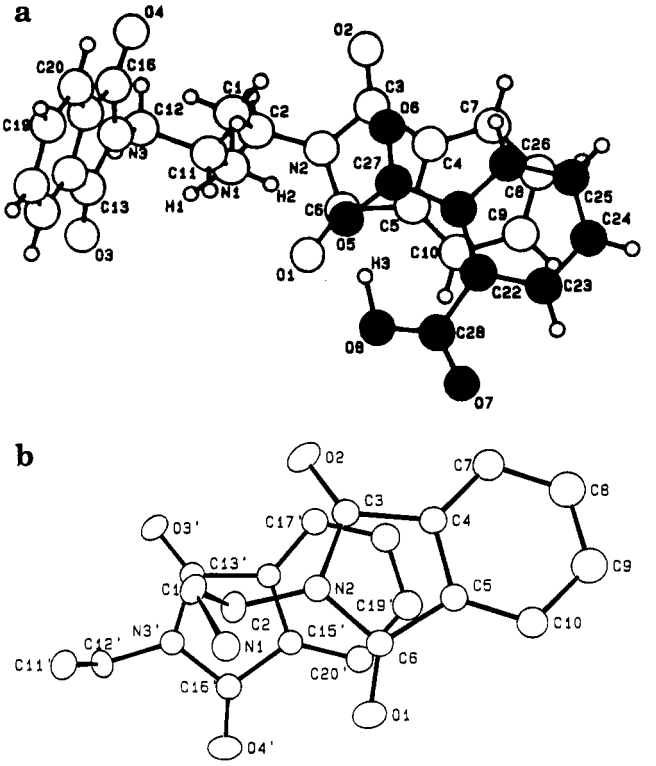
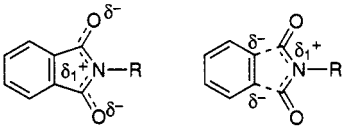


Figure 6. (a) Offset $\pi-\pi$ phthalimide–hydrogen phthalate stacks of **DPDAH–HP.** Atoms of hydrogen phthalate are shaded. (b) $\pi-\pi$ phthalimide–phthalimide stacks in **DPDAH–HP**. Primed atoms are related to the corresponding unprimed atoms of Figure 3 by the transformation $1-x, -1/2+y, -z$.

distances and angles compare well with previous determinations on similar species.[25-29]

The typically short phthalimide carbonyl bond lengths (1.203(2) Å and 1.207(2) Å (**2**), 1.201(3) Å and 1.209(3) Å (**3**), as well as 1.219(5) Å and 1.215(5) Å (**DPDAH–HP**)) and their high stretching IR frequencies (1700–1780 cm^{-1}) do not support the partial double bond character required by the frequently used phthalimide structural model **5**.[23]



5 **6**

That the phthalimide C=O bond is not involved in conjugative resonance is independently substantiated by ^{17}O NMR studies[30] in which aromatic or N-substituents were found to have only van der Waals, not electronic, effects on the chemical shift. However, partial double bond character in the phthalimide carbon–nitrogen bonds was convincingly demonstrated by C=N trapping reactions;[31,32] phthalimide C–N bond lengths (1.39–1.40

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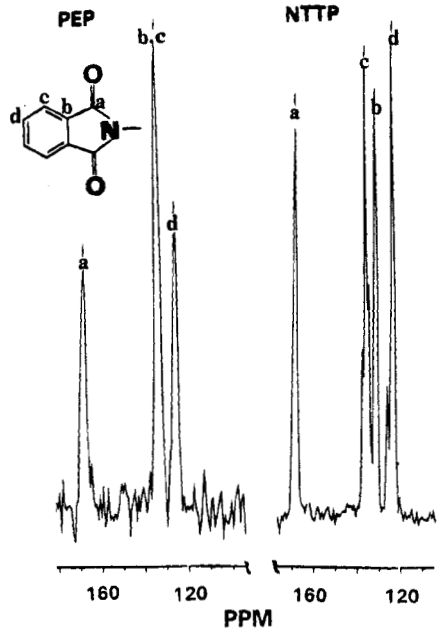


Figure 7. CP MAS ^{13}C NMR spectra of aromatic and carbonyl resonances for **2** and **3**.

Å), which are significantly shorter than single $C_{sp^2}-N_{sp^2}$ bonds (1.42 Å),[33] are also supportive. Whereas these data seem to suggest that the true solid state structure of the phthalimide moiety is close to **6**, the $C_{aryl}-C_{carbonyl}$ bond lengths (*ca.* 1.48 Å) are normal[34]—not unusually longer as would be expected. Further studies are thus needed to resolve the problem, but model **5** is unsatisfactory.

^{1}H and ^{13}C CP-MAS NMR Behavior. The most interesting ^{1}H NMR spectral region of the phthalimides studied is 7–8 ppm in which the four typically AB-type aromatic protons resonate.[35] The CH_2 resonances in the 2–4 ppm region are normal and, unlike their aromatic ^{1}H counterparts, are temperature independent. CP MAS ^{13}C spectra of powders of **3** (Figure 7) show two sets of aromatic carbon resonances which we attribute to the frozen structure shown in Figure 2 (i.e., the carbons interacting with the lone pair on the tertiary amine site and those which are not). If this solid state structure persists in solution two sets of AB aromatic proton resonances would be expected. However, a detailed study of the temperature evolution (178–420 K) of phthalimide AB aromatic ^{1}H resonances of **3** reveals one set of sharp, solvent dependent resonances throughout the temperature range (Figure 8). These results suggest that either the solution structure is close to that predicted by MM2 calculations (all three phthalimides fully extended), when the pyrrolic-amine interaction is not included, or the solid state conformation (Figure 2) undergoes rapid (on the NMR time scale) solution equilibration among the four isomers (Scheme 1).

Temperature dependent ^{1}H NMR spectral studies of **2** in chloroform and **DPDAH–HP** in DMSO reveal that, compared to **3**, the former compounds exhibit marginally temperature sensitive AB phthalimide resonances. This suggests that $\pi-\pi$ stacking interactions are not a significant source of the unusually high temperature sensitivity of resonances of **3**. In fact, effects of $\pi-\pi$ stacking interactions are detectable through studies of the concentration dependency of the aromatic ^{1}H NMR resonances of **DPDAH–HP** (for which $\pi-\pi$ stacking interactions were pronounced) and the **DPDA**/phthalic acid system. Whereas **DPDA** in DMSO exhibits concentration independent aromatic proton resonances (200 MHz; high frequency resonance = 1556 Hz), the aromatic phthalimide resonances of **DPDAH–HP** are significantly concentration dependent (higher frequency resonance = 1575 (dilute), 1570 (20 times more concentrated), and

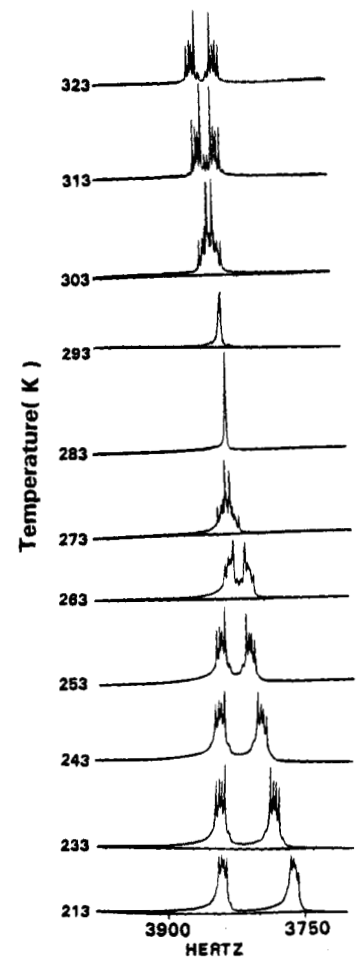
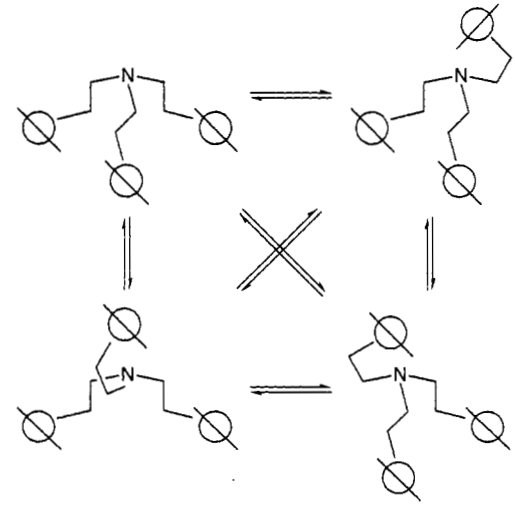


Figure 8. Spectacular temperature evolution of the aromatic ^{1}H NMR spectral profile (500 MHz) of **3** in chloroform.

Scheme 1. The Conformations of 3



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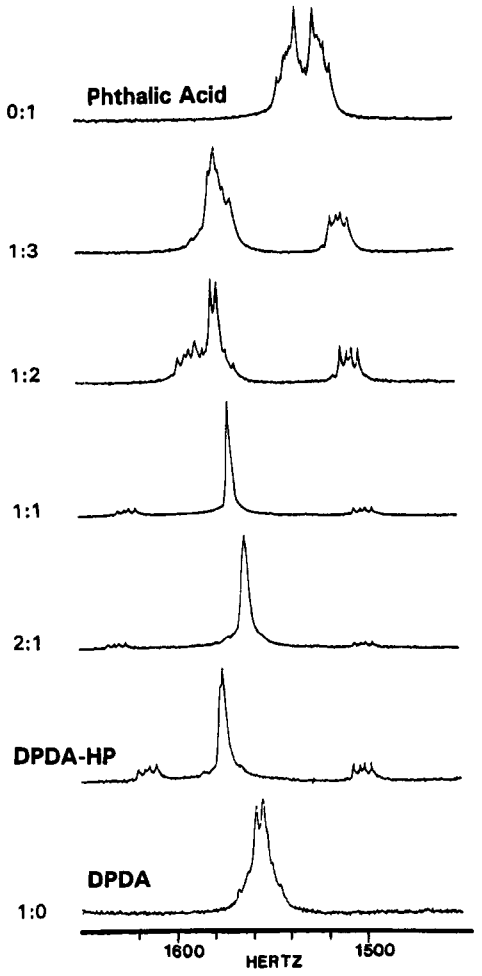

Figure 9. Dependence of the aromatic phthalimide and phthalate ^{1}H resonance on the initial **DPDA**-to-phthalic acid mole ratio in $(CD_3)_2SO$ (200 MHz).

1564 (saturated) Hz). These results indicate that the solid state extended intermolecular $\pi-\pi$ stacking interactions regime of **DPDAH−HP** (Figure 5) is present in solution. A titration of **DPDA** with phthalic acid (Figure 9) leads to the progressive downfield shift of the phthalimide proton resonances from 1556 to a limiting value of 1575 Hz corresponding to the phthalic acid-to-**DPDA** ratio of 2:1. It is also remarkable that the phthalate quartets, which are temperature independent in **DPDAH−HP**, are also narrow and dependent on the concentration of phthalic acid. This suggests that the **DPDAH−HP** ⇄ phthalic acid (**H_2P**) equilibration (eq 1) is fast on the NMR time scale. Similar studies with ethylene diphthalimide yielded concentration independent phthalimide and phthalate resonances.

$$\mathbf{DPDA} + \mathbf{H_2P} \rightleftarrows \mathbf{DPDAH{-}HP} \qquad (1)$$

From Figure 9 and eq 2,[36] the overall equilibrium constant for (1) is $K \simeq 4 \times 10^2$ L/mol, and the corresponding equilibration free energy ($\Delta G° = RT \ln K$) is $\Delta G° \simeq$ 14 kJ/mol. Since the phthalate ^{1}H resonances are temperature independent, equilibrium 1 is entropy driven.[37] We thus attribute the large temperature sensitivity of aromatic resonances of **3** to the amine−phthalimide interaction (Figure 2 and Scheme 1). Using the upper and lower δ limits in Figure 10a as δ_u and δ_b, respectively, and eq 8[36] we estimate the phthalimide−amine interaction enthalpy from Figure 10b (methanol and acetone) to be $\Delta H^‡ \simeq 20$ kJ/mol.

Experimental Section

Materials. 1a ($n = 2$, R = H) was 98% pure from Fisher Scientific Co., and absence of significant impurities was established by ^{1}H and ^{13}C NMR. Phthalic anhydride was 99.5% pure from BDH Chemicals Limited.

Elemental Analyses. Elemental analyses were performed by either Galbraith Laboratories, Knoxville, TN, or Medac Ltd., Brunel University, Uxbridge, U.K.

Spectral Measurements. Routine ^{1}H and ^{13}C NMR spectra, referenced to TMS, and CP-MAS ^{13}C NMR spectra were recorded at room temperature on a Bruker ACE 200 spectrometer at the University of the West Indies (UWI). All CP MAS ^{13}C NMR spectra were recorded with cross polarization, high power proton decoupling and magic angle spinning using 7 mm probes. The ^{13}C frequency was 50.325 MHz, and typical acquisition parameters were as follows: decoupler power, 80 W; contact time, 2 ms; recycle time, 2 s. Total spinning side band and nonquaternary carbon suppression procedures were used to aid the assignment. Variable temperature ^{1}H NMR spectra were recorded on either a Bruker AC200 (at UWI), General Electric 500 MHz spectrometer (Tulane University), or Bruker WM 250 MHz spectrometer (at Imperial College, U.K.). A Perkin-Elmer 1600 Series FTIR No. 16-1091 was used to record the IR spectra, and the mass spectra were obtained on a Kratos Concept 1 H spectrometer.

***N,N'*-Bis(2-phthalimidoethyl)piperazine (2).** A 7.49 g (50 mmol) portion of phthalic anhydride was slowly added to a stirring solution of 3.69 g (25.3 mmol) of triethylenetetraamine dissolved in 70 g of glacial acetic acid at room temperature. The resulting mixture was stirred at room temperature overnight and then refluxed for 1 h. Acetic acid was removed

(36) With c and y as initial concentrations of **H_2P** and **DPDA**, respectively, and the equilibrium concentration of **DPDAH−HP** = a, the overall equilibrium constant K for (1) is:

$$K = [\mathbf{DPDA{-}HP}]/[[\mathbf{H_2P}][\mathbf{DPDA}]] = a/[(c-a)(y-a)] \qquad (2)$$

Since equilibrium 1 is fast on the NMR time scale, the observed chemical shift (δ) is a weighted average of the rapidly exchanging aromatic phthalate ^{1}H resonances given by

$$\delta = \delta_b a/c + \delta_u(c-a)/c \qquad (3)$$

where δ_b and δ_u are the resonances of the aromatic phthalate protons in **DPDAH−HP** and **H_2P**, respectively. Equation 3 can be rearranged to yield

$$a = c[(\delta - \delta_u)/(\delta_b - \delta_u)] \qquad (4)$$

Substitution of a in (4) into (2) and rearranging yields

$$K = [(\delta - \delta_u)(\delta_b - \delta_u)]/[(\delta_b - \delta)[y(\delta_b - \delta_u) - c(\delta - \delta_u)]] \text{ (L/mol)} \qquad (5)$$

$\delta_b \simeq 1640$ Hz (i.e., δ corresponding to a solution containing a small amount of phthalic acid and excess **DPDA**), while that of $\delta_u \simeq 1533$ Hz (i.e., the experimentally observed aromatic ^{1}H resonance of free phthalic acid), $y \simeq 33$ mmol/L throughout and $c \simeq 18, 33, 66, 99$ mmol/L. Using the above arguments the observed aromatic proton resonance frequency (δ) of **3** will depend on limiting frequencies of the unbound (δ_u) phthalimide and phthalimide−amine complex (δ_b) (Figure 2 and Scheme 1) of **3** and the equilibrium mole fraction contributions of the two species (x and $(1-x)$, respectively) as $\delta = x\delta_b + (1-x)\delta_u$ from which

$$x = (\delta - \delta_b)/(\delta_u - \delta_b) \qquad (6)$$

The overall equilibrium constant, K, for the complexed and free phthalimide moieties in Scheme 1 is $K = x/(1-x)$, which upon substitution of x from eq 6 yields

$$K = (\delta - \delta_b)/(\delta_u - \delta) \qquad (7)$$

Using the van't Hoff equation and expression 7 we obtain

$$\ln K = \ln((\delta - \delta_b)/(\delta_u - \delta)) = \Delta H^‡/RT - \Delta S^‡/R \qquad (8)$$

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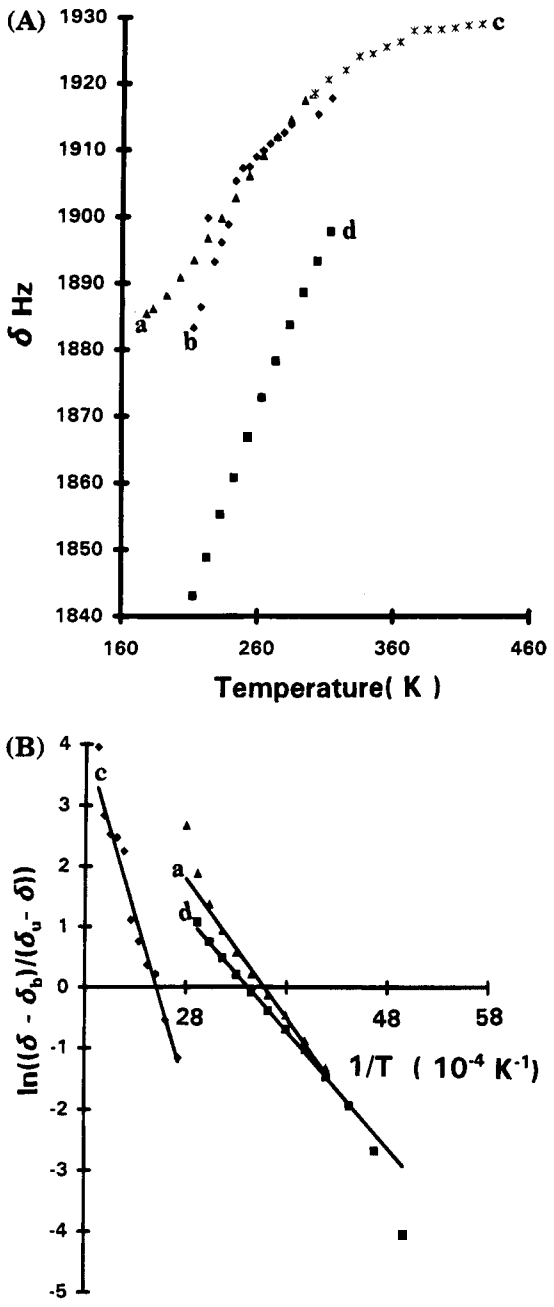

Figure 10. Temperature dependence of the AB aromatic phthalimide ^{1}H resonances (all data scaled to 250 MHz for comparison) of **3** (A) and the parameter[36] ln $((\delta - \delta_b)/(\delta_u - \delta))$ (B) (a = acetone, b = chloroform, c = DMSO, and d = methanol).

in *vacuo* and replaced with hot ethanol. Off-white needles (6.23 g, 58% yield based on phthalic anhydride) were deposited and subsequently recrystallized from ethanol: mp 256 °C; IR 1766 and 1706 cm^{-1} (imide); MS (electron impact) *m/z* 432 (M^+). Anal. Calcd for **2**, $C_{24}H_{24}N_4O_4$: C, 66.67; H, 5.55; N, 12.96. Found: C, 66.54; H, 5.52; N, 12.94.

***N,N′,N″*-(Nitrilotriethylene)trisphthalimide (3).** A 33.2 g (0.20 mol) portion of phthalic anhydride was added to a solution of 14.62 g (0.10 mol) of triethylenetetraamine dissolved in 160 g of glacial acetic acid (preheated to *ca.* 95 °C). This mixture was refluxed for 1 h and the solvent removed in *vacuo* and replaced with 95% ethanol. A total of 23.13 g (42% yield) of a pale yellow solid precipitated out. Recrystallization from an ethanol/$CHCl_3$ solvent system gave flat yellow-brown irregularly shaped crystals: mp 183 °C; IR 1766 and 1706 cm^{-1} (imide); MS (FAB, thioglycerol matrix) *m/z* 537 $(M + H)^+$. Anal. Calcd for **3**, $C_{30}H_{24}N_4O_6$: C, 67.16; H, 4.68; N, 10.45. Found: C, 67.40; H, 4.48; N, 10.40.

Table 1. Crystallographic Data for 2, 3, and DPDAH–HP

	2	3	DPDAH–HP
molecular form.	$C_{24}H_{24}N_4O_4$	$C_{30}H_{24}N_4O_6$	$C_{28}H_{23}N_3O_8$
molecular wt	432.25	536.51	529.24
cryst. size (mm)	0.3 × 0.3 × 0.4	0.36 × 0.16 × 0.53	0.23 × 0.40 × 0.59
cryst. shape, color	block, amber	plate, amber	plate, colorless
radiatn (graphite monochromated)	Mo Kα	Mo Kα	Mo Kα
crystal system	triclinic	triclinic	monoclinic
space grp	$P\bar{1}$ (No. 2)	$P\bar{1}$ (No. 2)	$P2_1$ (No. 4)
a, Å	7.2826(7)	8.57(1)	6.881(1)
b, Å	12.689(1)	20.435(4)	12.985(2)
c, Å	5.8575(8)	8.027(1)	13.818(2)
α, deg	91.085(8)	97.90(1)	
β, deg	96.018(8)	112.30(1)	101.03(5)
γ, deg	77.795(7)	79.42(1)	
V, Å^3	526.1(2)	1275(1)	1211.9(5)
Z	1	2	2
d_{calcd}, g cm^{-1}	1.36	1.40	1.45
range of data	$2\theta_{max} = 54°$	$2\theta_{max} = 50°$	$2\theta_{max} = 25°$
	$0 \le h \le 9$	$0 \le h \le 10$	$0 \le h \le 8$
	$-16 \le k \le 16$	$-24 \le k \le 24$	$0 \le k \le 15$
	$-7 \le l \le 7$	$-9 \le l \le 9$	$-16 \le l \le 13$
no. reflns collected	2485	4799	2435
no. unique reflns	2299	4473	2231
R_{int}	0.016	0.012	0.015
no. of reflns refined	1574 ($I \ge 2\sigma(I)$)	2965 ($I \ge 2\sigma(I)$)	1855 ($I \ge 3\sigma(I)$)
no. of variables	193	361	273
R	0.037	0.054	0.046
wR	0.050	0.064	0.063
S	1.676	2.027	2.186

Diphthalimidodiethylammonium–Hydrogen Phthalate (DPDAH–HP). To a solution of 10.30 g (0.10 mol) of diethylenetriamine (**DETA**) dissolved in 160 g of acetic acid was added 33.2 g (0.20 mol) of phthalic anhydride. This mixture was left to reflux for 1 h, and then the acetic acid was removed in *vacuo* and replaced with ethanol. A total of 22.58 g (64% yield) of a cream crystalline precipitate was obtained. Recrystallization gave thick transparent plates: mp 176–177 °C. Anal. Calcd for **DPDAH–HP** $C_{28}H_{23}N_3O_8$: C, 63.52; H, 4.35; N, 7.94. Found: C, 63.44; H, 4.37; N, 7.91. This compound is also obtained by reacting directly phthalic acid with **DPDA**.

X-ray Crystallography. Crystals of **2**, **3**, and **DPDAH–HP**, obtained as described above, were mounted on thin glass fibers with a film of epoxy cement. General procedures for crystal orientation, unit cell determination, and refinement and collection of intensity data on the CAD-4 diffractometer have been published.[38] Details specific to the present study are summarized in Table 1. For **2** and **3**, no indication of cells of symmetry higher than the triclinic ones indicated by the CAD-4, software[39] could be detected by a Niggli reduction or by diffraction symmetry, and the initial choices were confirmed by the successful refinement. For **DPDAH–HP**, the initially determined monoclinic cell was confirmed by the observation of *2/m* diffraction symmetry. No significant variations in the intensities of three monitored reflections were observed for any of the crystals during the data collections. The data were corrected for Lorentz and polarization effects but not for absorption. No indication of the need for an extinction correction was seen. All structures were solved by direct methods (SIR 88)[40] which provided locations for virtually all the non-hydrogen atoms.

The solution and refinement of **3** in $P\bar{1}$ proceeded uneventfully, while for **2**, since the composition was initially unknown and proposed formulations were noncentrosymmetric, the solution was first attempted in the noncentric space group *P1*. The solution obtained was clearly centrosymmetric, so refinement was carried out in $P\bar{1}$. Following full-matrix, least-

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squares refinement of both structures with anisotropic displacement parameters for all non-hydrogen atoms. $\Delta\varrho$ maps provided locations for all hydrogen atoms for **2** and the majority of those for **3**. Refinement of **2** was completed by inclusion of the hydrogen atoms with refinement of their positional and isotropic displacement parameters. For **3** the hydrogen atoms were included as fixed contributions in idealized positions (C−H = 0.95 Å) with isotropic displacement parameters **20%** larger than those of the attached carbon atoms and updated periodically. Both final $\Delta\varrho$ maps were essentially featureless.

For **DPDAH−HP**, the only systematic absence observed in the final data set was *0k0* for *k* odd indicating the space group to be either $P2_1$ or $P2_1/m$. Although not conclusive, the intensity statistics tended to favor the former, and this choice was further supported by the fact that a resonable calculated density could only be obtained with the assumption that $Z = 2$. This was confirmed by the successful refinement using full-matrix, least-squares methods, isotropic displacement parameters for the carbon and nitrogen atoms of the phthalimido moieties, and anisotropic displacement parameters for the remaining non-hydrogen atoms. Following location of most hydrogen atoms in a $\Delta\varrho$ map, the refinement was completed by also refining the positional and isotropic displacement parameters of the hydrogen atoms attached to N(1) and O(8) and inclusion of the remainder in calculated positions as described above for **2** and **3**.

For all structures, weights, $w_i = 4F^2/[\sigma(I)^2 + (0.04F^2)^2]$, were used in the final refinement. Scattering factors were taken from *International Tables for X-ray Crystallography* (1974, Vol. IV). All calculations were performed in a VAX station 3100 with the *MolEN* suite of programs.[41,42]

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Supporting Information Available: Tables giving crystal data and details of structure determinations, atom coordinates, all bond lengths and angles, anisotropic thermal parameters, and hydrogen locations (81 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO9413092

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(42) The author has deposited atomic coordinates for **2**, **3**, and **DPDAH−HP** with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.