Surprises in a 'Simple' System: 2,4-Diaminobenzenesulfonic Acid

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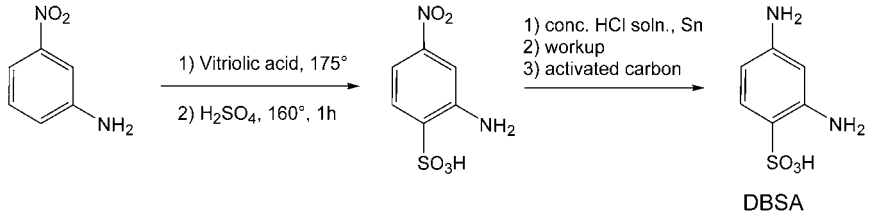
Dedicated to Professor *Jack D. Dunitz* on the occasion of his 80th birthday

The search for the polymorphic forms of 2,4-diaminobenzenesulfonic acid (DBSA), known to exist since 1880, has revealed a surprisingly rich solid-state system for such a simple molecule. A monohydrate, a dimoiric hydrate, an anhydrate and two polymorphic forms of the hydrochloride of this material have thus far been prepared. Their characterization by microscopic and thermal methods, FT-IR spectroscopy, and single-crystal structure determination are described.

1. Introduction: Historical Background. – *Groth*'s classic collection of the characterization of over 8000 crystalline compounds, mainly by interfacial angles, also contains many observations of much crystal chemistry, including polymorphism [1]. One example is 2,4-diaminobenzenesulfonic acid (DBSA) originally described as brown monoclinic plates and colorless or weakly brown triclinic prisms [2][3]. *Groth* [1] also cited this compound in what is, to the best of our knowledge, the first list of concomitant polymorphs [4]. The 2,4-diaminobenzenesulfonic acid was initially prepared by *Post* and *Hardtung* [2] according to *Scheme 1*, which yielded two dimorphic modifications. Their findings were confirmed in a thesis by *Levin* [5].

Scheme 1

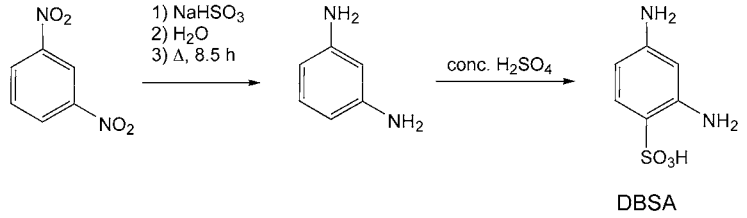


The concomitant polymorphism observed in the 1880's was not reported again until 1931 when *Hunter* and *Sprung* [6] studied examples of the so-called *Piria* reaction, according to *Scheme 2*.

After purification by filtration and extraction with alcohol and H_2O two distinct modifications of 2,4-diaminobenzenesulfonic acid were obtained, described as 'large monoclinic plates and elongated prisms'.

The 2,4- and 2,5-diamino derivatives have long been used as starting materials for the preparation of azo dyes [7][8], and more recently in the manufacture of copolyamides [9]. However, no further mention of the polymorphism of DBSA has been reported in the more recent literature.

Scheme 2



DBSA

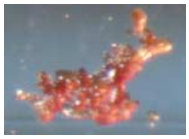
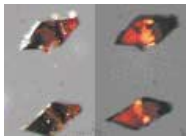
As part of an investigation of the series of concomitant polymorphs originally given by *Groth* [1], we undertook a study of the solid-state chemistry of DBSA, which proved to be far richer than originally suspected. In the course of this investigation, we isolated an anhydrate (DBSA), a monohydrate (DBSA1W), a dimoiric hydrate (DBSA⅔W), and two polymorphic forms of the hydrochloride (DBSAHCl1 and DBSAHCl2) of this material (see below, *Table 3*). However, in spite of considerable efforts we have not yet succeeded in reproducing the second polymorph of the anhydrate, reported by *Post* and *Hartung* [2] and *Hunter* and *Sprung* [6], suggesting that this might be a case of a disappearing crystal form [10], even though *Groth* and/or previous authors apparently succeeded in obtaining well developed crystals. The characterization and comparison of the various crystal forms by optical microscopy, single-crystal and powder X-ray diffraction, FT-IR, mass spectrometry, and thermogravimetric analysis (TGA) is reported here.

2. Results. – 2.1. *Preparation of Crystal Forms.* DBSA is fairly soluble in H_2O, sparingly soluble in MeOH and EtOH, and when recrystallized from these solvents, at least three weeks are generally required to produce even poor quality crystals. Whenever any crystal of sufficient quality (and we use this term quite loosely) for single crystal analysis was obtained, a data set was immediately measured. In this way, we discovered that the crystal habit is not always a good indication of crystal form [11] and that the differences in crystal habit may not be indicative of polymorphism for this system.

Several crystal habits of the DBSA were obtained from different crystal growth conditions (*Table 1*). The crystal habits of the material are quite diverse: brown plates, brown needles, and colorless plates, which appear concomitantly, and flattened diamonds. The zwitterionic 4-aminobenzenesulfonic acid monohydrate is also known to crystallize in two crystal habits – 'elongated monoclinic laths and rhombic plates' [12].

Attempts to make the '*m*-diamidobenzenesulfonic acid' as DBSA is called by *Groth* [1] – initially thought to be the 3,5-substituted derivative but now known to be the 2,4-substituted derivative – by the method suggested by *Post* and *Hardtung* [2] (see *Scheme 1*), produced a beige crystalline powder, which on analysis by TGA, proved to be the monohydrate denoted DBSA1W; the original beige powder did not contain crystals of sufficient size for single-crystal X-ray analysis. After several days of standing in the remaining mother liquor, a second type of crystal – orange-brown prisms – was observed and was suitable for single-crystal X-ray analysis; however, the prisms proved

Table 1. *Growth Conditions for Various Crystal Habits of DBSA*

Crystal description	Photograph	Growth conditions and comments
Brown plates		Saturated aqueous solution at 13° after standing for several weeks
Diamond shaped crystals with a flattened end		Vapor diffusion of acetone into a saturated aqueous solution at 22°; several batches of crystals were obtained but only the first one showed this habit; subsequent batches had the plate-like habit
Brown needles and faintly brown-colorless plates, concomitantly		Saturated aqueous solution with dil. AcOH solution at 60°, by slow evaporation
Orange-brown needles		Saturated aqueous solution in 0.5-mm-diameter capillary tubes at 22°, by slow evaporation

to be the 2,4-diaminobenzenesulfonic acid dimoiric hydrate (gr. = ⅔, *i.e.*, three molecules of DBSA and two molecules of H_2O in the asymmetric unit) denoted DBSA⅔W. The DBSA1W and DBSA⅔W were subsequently found to exist concomitantly in the sample vial.

DBSA⅔W can also be produced from saturated aqueous solution under several different conditions (*Table 2*). It should be noted that only experiments conducted at room temperature (22°) produced this hydrate. All of the examples were verified by full single crystal analysis to be the dimoiric hydrate.

The growth conditions of the two polymorphs of the 2,4-diaminobenzenesulfonic acid hydrochloride are quite similar. DBSAHCl1 was obtained first; it was grown from a saturated aqueous solution with dilute HCl solution at 60° by slow evaporation over several weeks. This produced opalescent plates and prisms (*Fig. 1,a*). Subsequent attempts to reproduce this experiment have thus far been unsuccessful, and may indicate that this is another example of a disappearing crystal form [10]. However, changing the temperature of crystallization to 35° resulted in the concomitant crystallization of DBSAHCl1 and DBSAHCl2, exemplifying the principle that once a polymorphic form has been obtained, it should always be possible to produce it again – although not necessarily under the same conditions [10].

Table 2. *Growth Conditions for 2,4-Diaminobenzenesulfonic Acid Dimoiric Hydrate* (DBSA$^2/_3$W)

Crystal description	Photograph	Growth conditions
Brown plate		Saturated aqueous solution at 22° by slow evaporation
Pale brown plates		Vapor diffusion of MeOH into a saturated aqueous solution at 22°
Brown-colorless plates		Saturated aqueous solution with dil. HCl solution at 22°
Initially clear brown fragments; then half the crystals became beige and polycrystalline while maintaining their original morphology, and the remainder became dark brown in color		Saturated aqueous solution at 22°
Blocky colorless crystals		Saturated aqueous solution at 22°, vial scratched to induce kinetic crystallization
Colorless plates		Saturated aqueous solution at 22°

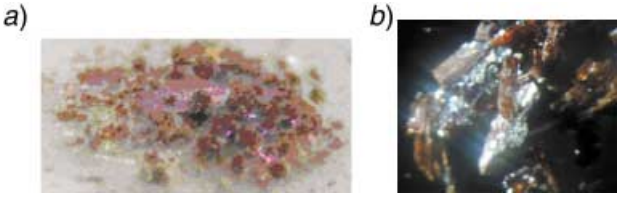


Fig. 1. *Photographs of* a) *DBSAHCl1 and* b) *DBSAHCl2*

DBSAHCl2 also tends to decompose on standing for several months into a beige powder, similar in shape and form to that of the anhydrate powder, and giving a microscope FT-IR spectrum identical to that of the anhydrate. DBSAHCl2 was obtained by slow evaporation from a saturated aqueous solution containing three drops of conc. HCl solution at 45°. These crystals tend to be brown cubes growing in clusters and tend to be multiply twinned. They do not display the same opalescence as that seen in DBSAHCl1 (*Fig. 1,b*).

2.2. *Single-Crystal X-ray Analysis.* Thus far, we have determined the single crystal structures of the following crystal forms of 2,4-diaminobenzenesulfonic acid: DBSA, DBSA⅔W, and two polymorphs of the DBSAHCl (*Table 3*). In all of the structures obtained, the molecule is zwitterionic, resulting from a transfer of the H-atom from the SO_3H group to the *para*-NH_2 group. The 4-aminobenzenesulfonic acid is known to exist as a zwitterion in solution, as well as in the solid state [12][13]. There is no reason to suppose that this should not be true of DBSA as well.

Table 3. *Crystallographic Data for Various Forms of 2,4-Diaminobenzenesulfonic Acid*

	Anhydrate	Dimoiric hydrate	Hydrochloride Form I	Hydrochloride Form II
Abbreviation	DBSA	DBSA⅔W	DBSAHCl1	DBSAHCl2
Empirical formula	$C_6H_8N_2O_3S$	$C_6H_8N_2O_3S \cdot ⅔\ H_2O$	$C_6H_9ClN_2O_3S$	$C_6H_9ClN_2O_3S$
Crystal system	monoclinic	triclinic	orthorhombic	monoclinic
Space group	$P2_1/c$	$P\bar{1}$	$Pbca$	$P2_1/n$
a [Å]	7.958(2)	9.9611(6)	13.448(1)	6.391(7)
b [Å]	5.824(1)	10.9142(6)	7.8085(9)	9.68(1)
c [Å]	15.476(3)	12.3683(8)	16.585(2)	14.08(1)
α [°]		91.405(3)		
β [°]	98.78(3)	109.056(2)		90.55(2)
γ [°]		105.654(2)		
Volume [Å^3]	708.9(2)	1214.4(1)	1741.6(3)	871.2(2)
Z	4	6	8	4
Density (calc.) [g/cm^3]	1.756	1.643	1.714	1.713
R_1	0.0415	0.0343	0.0401	0.0601

A comparison of the S–O bond lengths in the various forms of DBSA reveals no major differences, indicating that there is no evidence of distinct single and double bonds [14]. Also an examination of the C–N bond lengths reveals the expected bond lengths for NH_3^+ and NH_2 groups [15]. These data and the location of the NH_3^+ H-atoms from the difference maps (all with full occupancy) support the zwitterionic nature of the material. This is in good agreement with the structures of 2-amino-

benzenesulfonic acid (OTANAC) [16], 3-aminobenzenesulfonic acid (ANISAC)[1]) [17], and 4-aminobenzenesulfonic acid (AFAZEM) [14] and its monohydrate (SANACM) [12].

The ORTEP diagram of the asymmetric unit of DBSA (*Fig. 2*) clearly displays the zwitterionic nature of the molecules of 2,4-diaminobenzenesulfonic acid in the various crystal forms. The hydrochlorides possess an additional H-atom at $NH_2-C(2)$, with a Cl^- counterion.

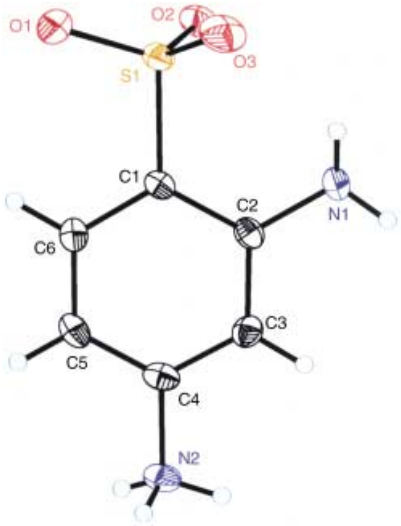


Fig. 2. *ORTEP Diagram and atomic numbering of the asymmetric unit of DBSA*. Note: all the crystal structures follow the same atomic-numbering system.

The crystals of DBSA⅔W possess $Z = 6$, *i.e.*, with $Z' = 3$ (*Fig. 3*). $Z' = 3$ is quite rare with only 2138 such structures out of more than 272066 entries in the November 2002 release of the *CSD*, of which 247 are found in space group $P\bar{1}$. Two of the molecules tend to pack in a pairwise fashion with overlapping aromatic rings and the SO_3^- group and the NH_3^+ group at C(4) of two adjacent molecules one above the other, while the third molecule is off to one side at an angle to the plane of the two other benzene rings.

As can clearly be seen from the stereoviews of the packing diagrams (*Fig. 4*), the structures of the various crystal forms are quite different. The reference molecule (displayed as a ball-and-stick structure) has been chosen with the same orientation in all of the structures displayed in *Fig. 4*, *i.e.*, on the plane of the benzene ring with the SO_3^- group on the vertical and $NH_2-C(2)$ pointing to the left. However, the presence of a primary ammonium ion will bring anions closer together, by H-bonding to at least two different anions, forcing layered sheets to form [18]. As such, we expect this packing motif to be present in all of these structures.

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[1]) REFCODE from the *Cambridge Stuctural Database* (*CSD*), November 2002 edition.

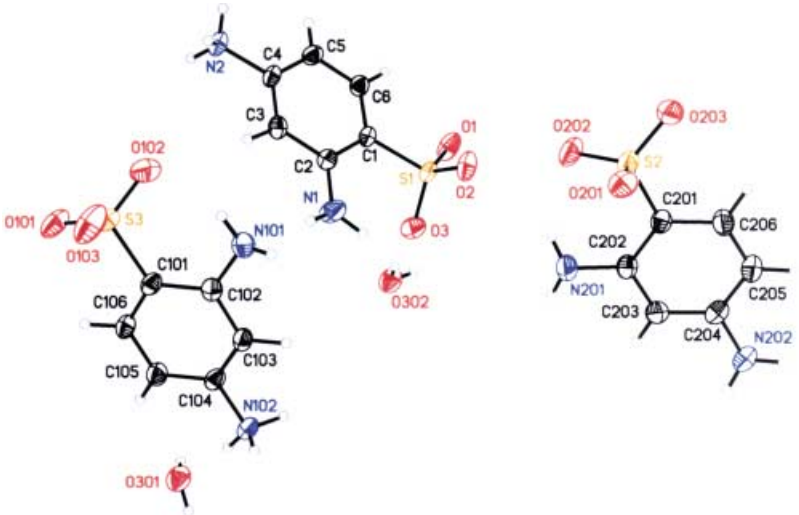

Fig. 3. *ORTEP Diagram and atomic numbering of the three molecules of 2,4-diaminobenzenesulfonic acid and two molecules of water in the asymmetric unit of DBSA⅔W*

The asymmetric units of the two polymorphic forms DBSAHCl consist of a molecule that is not just zwitterionic but has three charges at the benzene ring, both amino NH_2 groups being positive (2 NH_3^+ and the sulfonic acid group being negative (1 SO_3^-) with a Cl^- counterion, as required by the chemistry of this salt. It should be noted that there is no other structure with multiple charges at a benzene ring without stabilization by large bulky substituents listed in the November 2002 release of the *CSD*.

In the stereoview of the packing diagram of DBSA (*Fig. 4,a*), it can be seen that the molecules tend to pack as two parallel rows of molecules all orientated with their benzene rings in the plane of the paper followed by another two rows of molecules with their long axes perpendicular to them.

The stereoview of DBSA⅔W (*Fig. 4,b*) also shows that the molecules pack as pairs head to tail, with their long axes parallel and their $NH_2-C(2)$ pointing in the same direction. The overlap between aromatic rings is far from complete. The pairs tend to pack as rows with alternating rows of molecules in the plane of the paper (running vertically) and almost perpendicular to it. The H_2O molecules lie in the voids between the rows of molecules.

In DBSAHCl1, the molecules tend to pack as parallel sheets with pairs of molecules head to tail along the long axis of the molecule (*Fig. 4,c*). The $NH_2-C(2)$ groups point in opposite directions. There is only partial overlap of the aromatic rings in the pairs of molecules.

In DBSAHCl2, the molecules pack in rows parallel to the *c*-axis with pairing with almost complete overlap of the aromatic rings, but with an angle of *ca.* 58° between their SO_3^- groups (*Fig. 4,d*). Again, the NH_2 groups lie on opposite sides of the benzene rings. Alternate rows of molecules are not parallel to each other.

2.3. *Hydrogen Bonding and Graph-Set Analysis.* The H-bonding in the structures is shown in *Fig. 4*. Graph-set analysis [19] [20] with the aid of PLUTO [21] were utilized to characterize and compare the H-bond patterns in the four structures. A comparison of the graph-set matrices [20] (*Tables 4* and *5*) of the two hydrochloride polymorphs clearly revealed the similarities and differences in the H-bond patterns of the two crystal forms. Three first-order H-bond motifs are common to both forms: $C(8)$ from the *para*-amino group; $C(6)$ and $S(6)$ from the *ortho*-amino group, with no matching second-order graph sets .

The three graph sets common to the two hydrochlorides are also common to the anhydrate. The anhydrate also shares an additional H-bond pattern with each of the hydrochloride polymorphs: $C(6)$ with DBSAHCl1 and $R_2^2(16)$ with DBSAHCl2. Hence these patterns appear to be characteristic of the packing mode of DBSA in a variety of structures.

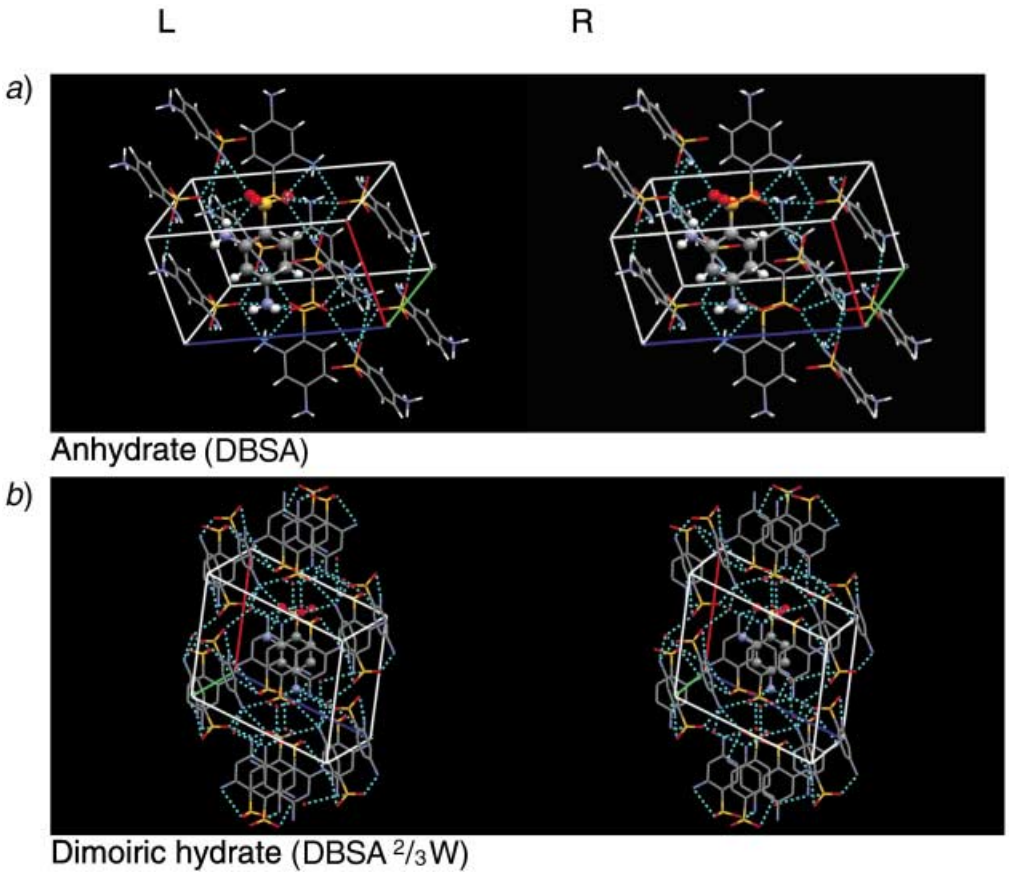

Fig. 4. *Stereoviews of the unit cells of* a) *DBSA* b) *DBSA⅔W*, c) *DBSAHCl1, and* d) *DBSAHCl2.* The view is on the best plane of the benzene ring with the sulfonate group on the vertical and the NH_2 group at C(2) to the left; the reference molecule is displayed as a ball-and-stick model. H-Atoms are omitted for clarity.

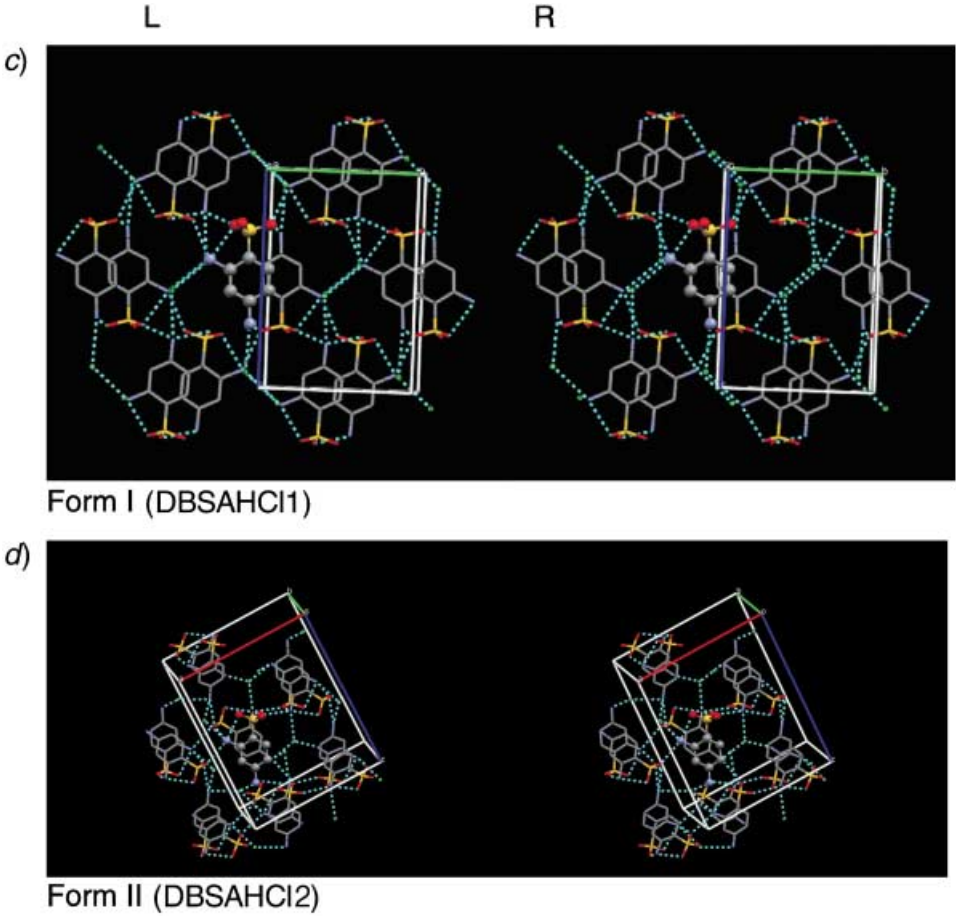

Fig. 4 (cont.)

In DBSA⅔W, each of the three molecules in the asymmetric unit has one H-bond from a H_2O H-atom to the SO_3^- group, and one H-bond to the H_2O O-atom from a H-atom of the amino at C(4) of the benzene ring. The graph-set matrix of DBSA⅔W (not shown) is far more complex than those of the other forms due to the presence of the three molecules of 2,4-diaminobenzenesulfonic acid in the asymmetric unit (*Fig. 4*, *b*). The $Z' = 3$ situation leads to many first- and second-level entries, which are *D* (discrete). The ring (*R*) and chain (*C*) patterns will appear for higher-level graph sets [20]. There are an additional seven H-bonds between the H_2O molecules and the DBSA molecules, all of them are of the *D*(2) H-bond type. The additional bond is to the SO_3^- group of the central DBSA molecule (*Fig. 4*, *a*). The $NH_2-C(2)$ does not participate in H-bonding with the H_2O molecules. Initially, ignoring the H-bonds for the H_2O molecules, in graph-set terms at the first level, the H-bond patterns of the three molecules in the asymmetric unit are similar. Typical of structures with $Z' > 1$, there are

Table 4. *First- and Second-Level H-Bond Graph-Set Matrix of DBSAHCl1*

	a	**b**	**c**	**d**	**e**
a	$C(8)$	$C_2^2(10)$	$C_2^2(10)$	$C_2^2(10)$	
b	$C_2^2(14)$	$C(6)$	$C_2^2(6)$	$R_4^2(8)$	
c	$C_2^2(14)$	$R_2^2(12)$	$C(6)$	$R_4^4(12)$	
d	$C_2^2(14)$	$R_4^4(24)$	$R_4^4(24)$	$C(6)$	
e					$S(6)$

Table 5. *First- and Second-Level H-Bond Graph-Set Matrix of DBSAHCl2*

	a	**b**	**c**	**d**	**e**
a	$C(8)$	$C_2^2(16)$	$C_2^2(6)$	$R_4^4(20)$	
b	$C_2^2(16)$	$R_2^2(16)$	$C_2^2(6)$	$C_2^2(10)$	
c	$C_2^2(16)$	$C_2^2(16)$	$R_2^2(16)$	$C_2^1(8)$	
d	$R_4^4(28)$	$C_2^2(14)$	$C_2^2(14)$	$C(6)$	
e					$S(6)$

a number of *D* patterns. In addition, two of the three molecules participate in $R_2^2(16)$ patterns, while the third molecule is involved in a $R_2^2(12)$. At the second level, $D_3^3(13)$ is a pattern common to all three molecules.

Since H-bonds are primarily electrostatic in nature [18], they may be enhanced by the presence of charge at either the donor, the acceptor, or both atoms [22]. Thus, one would expect the strength of such H-bonds to increase, and their length to decrease – although there has been doubt cast upon this premise [23]. In looking at the H-bond lengths of DBSAHCl1 in *Table 6*, virtually all of them may be considered to be 'strong' H-bonds, being less than the sum of their *van der Waals* radii [22]. Consistent with that view, these charge-assisted bond lengths in *Table 6* fall at the lower end of the range of $N^+-H\cdots O^--S$ bond lengths when both charged groups are at the same benzene ring (1.81 – 2.92 Å for 21 cases from the November 2002 release of the *CSD* [21]).

Table 6. *H-Bond Lengths $N^+H\cdots O^-S$ in the two forms of DBSAHCl*

	DBSAHCl1	DBSAHCl2
$N(1)-H\cdots O(1)-S$ (internal)	2.35	2.52
$N(1)-H\cdots O(1)-S$	2.39	–
$N(1)-H\cdots O(2)-S$	1.93	2.00
$N(1)-H\cdots O(3)-S$	1.96	–
$N(2)-H\cdots O(1)-S$	–	1.93
$N(2)-H\cdots O(2)-S$	–	2.09
$N(2)-H\cdots O(3)-S$	2.36	2.12

2.4. *Thermal Analyses.* 2.4.1. *Methods.* Differential scanning calorimetry (DSC), TGA, and optical hot-stage microscopy have been used individually and in combination to elucidate the thermal properties of the various crystal forms. The combination of DSC and optical hot-stage microscopy has proved to be a very valuable tool in understanding this system.

2.4.2. *DBSA*. The peak between 185–195° (*Fig. 5*) in the DSC thermogram of DBSA corresponds to cracking of the crystals and the evolution of a gas as observed sequentially by hot-stage microscopy (*Fig. 6*). The rough nature of the peak may be accounted for by the sequential transformation of successive microcrystalline areas.

TGA on the same material (*Fig. 7*) gives no indication of any weight loss at this temperature. The only peak seen represents the decomposition of the material at and above its reported melting point of 260–266° [24]. It should be noted that while this melting point is listed in the *Fluka* catalogue, we have not observed it, *i.e.*, this material, like the other DBSA derivatives, begins to decompose rather than melt at this temperature. There is no TGA event corresponding to the peak seen at *ca.* 185–195° in the DSC thermogram of the anhydrate, and no corresponding observation of gas evolution at this temperature when observed under silicon oil by hot-stage microscopy.

2.4.3. *DBSA⅔W*. The DSC thermogram of DBSA⅔W (*Fig. 8*) shows a large endothermic peak at *ca.* 115°. Correlation with the TGA (*Fig. 9*) indicates that this peak

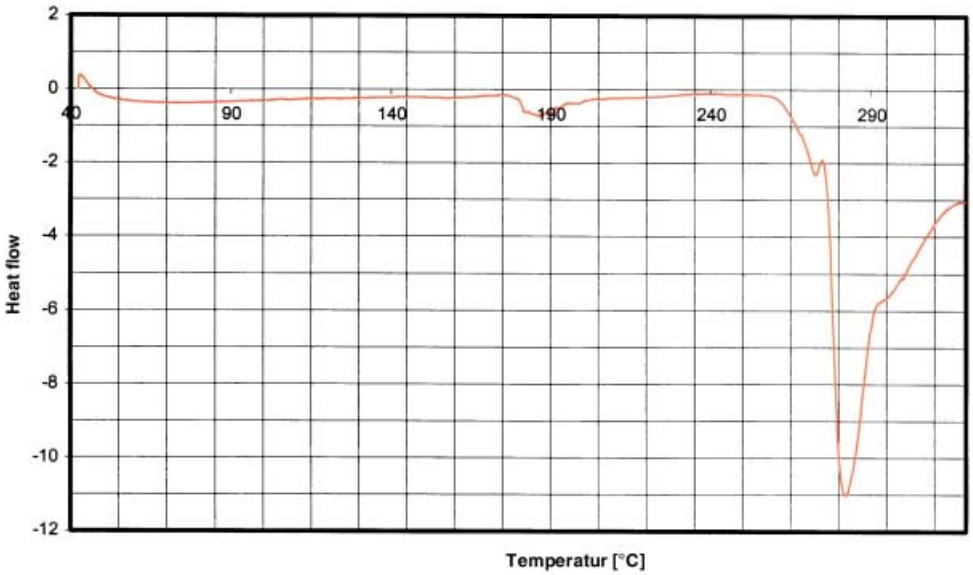

Fig. 5. *DSC Thermogram of DBSA*

Fig. 6. *Cracking and darkening followed by evolution of bubbles from a single crystal of DBSA*. The entire sequence (from left to right) occurs in less than 20 s.

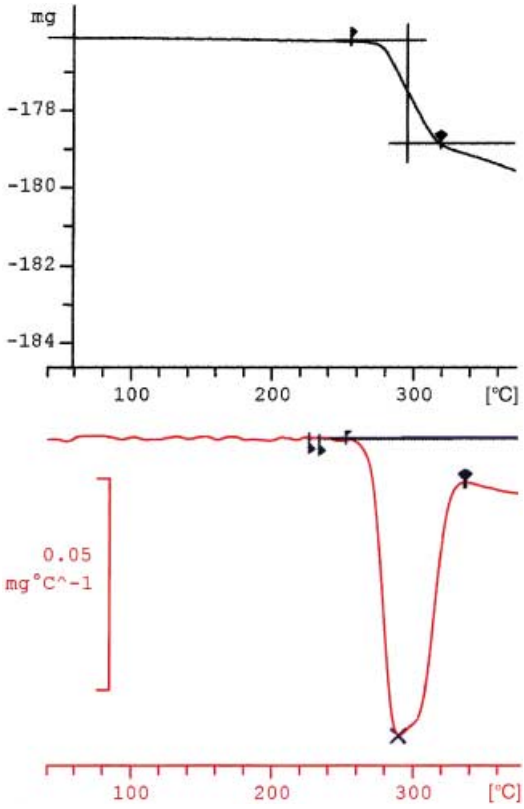

Fig. 7. *TGA Thermogram of DBSA*

corresponds to the dehydration of the material to the anhydrate, followed by decomposition. The dehydration may be followed by hot-stage microscopy of the crystals under silicon oil. It is characterized by a darkening of the crystals, which is followed by rapid production of bubbles indicating the escape of H_2O vapor from the crystals. That this is seen as one peak in the DSC and TGA suggests that the two crystallographically independent H_2O molecules are bound equally well in the DBSA⅔W crystal lattice. There appears to be an exothermic event at *ca.* 260°, just before the onset of decomposition, no concurrent event was observed by optical hot-stage microscopy. The unevenness of the decomposition peak may be caused by differences in the sizes of the crystals in the pan and their relative amounts of exposed surface area.

The TGA thermogram (*Fig. 9*) indicates a ratio of 2 molecules of material to 1 molecule of H_2O – quite different from the 3 : 2 ratio obtained from single-crystal X-ray diffraction. However, there is evidence that the material dehydrates partially on standing. Sample vials containing crystals of previously brown plates were seen to contain both the brown crystals and a beige powder on standing at room temperature for an extended period of time (*Fig. 10*). The beige material was found to be amorphous on examination by X-ray diffraction, and its microscope FT-IR spectrum

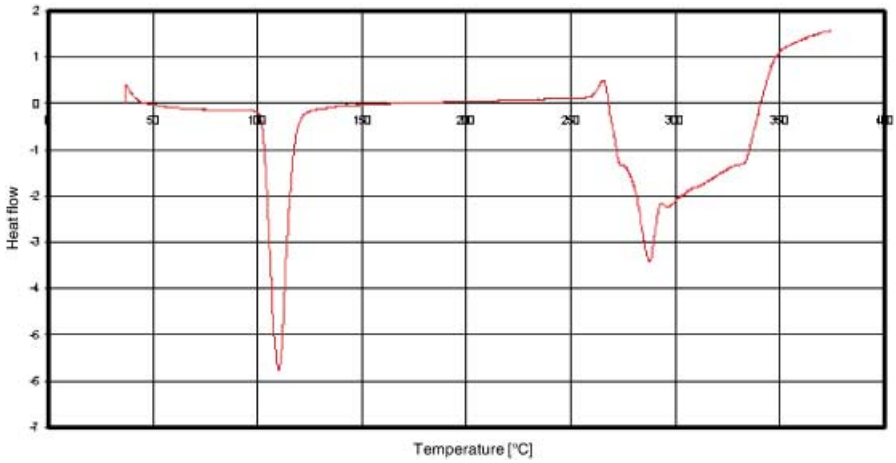

Fig. 8. *DSC Thermogram of DBSA⅔W*

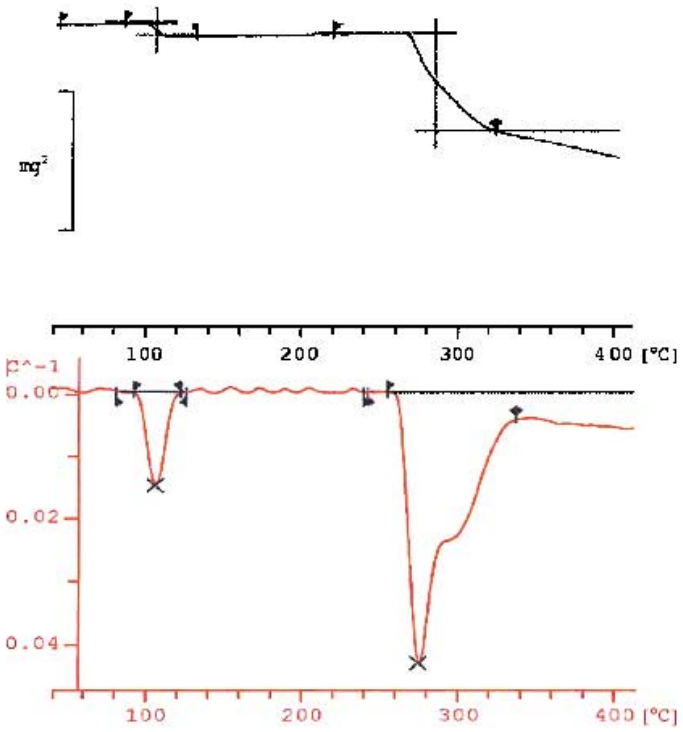

Fig. 9. *TGA Thermogram of DBSA⅔W*

differs from all of the other 2,4-diaminobenzenesulfonic acid derivatives. TGA of a similar powder from another vial was consistent with the existence of a monohydrate of 2,4-diaminobenzenesulfonic acid, although we have not yet investigated this further.

Fig. 10. *Photograph of a sample of DBSA⅔W containing both brown crystals and the beige material described in the text*

2.4.4. *DBSAHCl1 and DBSAHCl2.* The DSC thermograms of the two polymorphs DBSAHCl (*Fig. 11*) are quite different. That of DBSAHCl1 reveals only 1 endothermic peak, at *ca.* 273° on decomposition. The ΔH of this peak is -125.73 kJ/mol. This corresponds well to its behavior observed under a hot-stage microscope, where at $271 \pm 3°$ the crystals begin to produce bubbles, and then at 291.5°, the crystals begin to darken while continuing to produce bubbles. However, there is no observed thermal event in the DSC thermogram corresponding to the observed darkening in color of the crystals at $68 \pm 2°$.

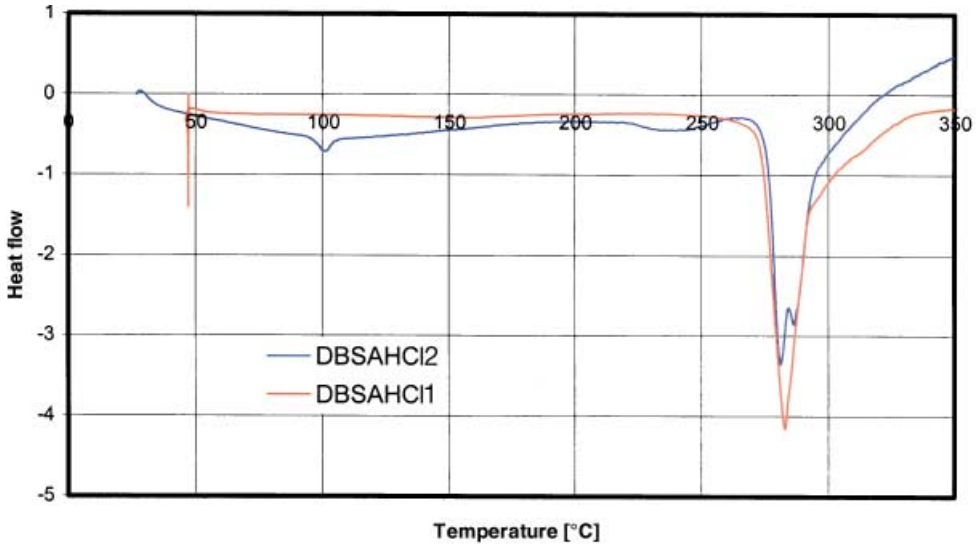

Fig. 11. *DSC Thermograms of DBSAHCl1* (red) *and DBSAHCl2* (blue)

DBSAHCl2 displays two endothermic peaks (onset temperatures at *ca.* 95° and *ca.* 214°, resp.) before the split decomposition peak at the same temperature as that of DBSAHCl1. The lower-temperature peak has a ΔH of 2.79 kJ/mol and is consistent with a darkening of the crystals observed by hot-stage microscopy. The second, broader peak has a ΔH of 7.57 kJ/mol and does not correspond to any phenomenon observed by hot-stage microscopy. The double-peaked endotherm at *ca.* 280° has a smaller ΔH (– 80.25 kJ/mol) than that of DBSAHCl1 (– 125.73 kJ/mol); it corresponds well to the observed darkening and onset of decomposition observed by hot-stage microscopy at 278.2°. From the sequence of the appearance of the two crystal forms, DBSAHCl2 is expected to be more stable than DBSAHCl1, in accordance with *Ostwald*'s rule of stages.

2.5. *FT-IR Spectroscopy.* Due to the known tendency [2][6] of DBSA to crystallize concomitantly and because of the variety of observed crystal habits, bulk analysis proved uncertain. All the FT-IR spectra were measured by microscope FT-IR as this allowed the analysis of single crystals of material, as well as possibly different crystal forms resulting from the hot-stage experiments.

The FT-IR spectrum of DBSA⅔W displays the characteristic broad peak at 3350 cm^{-1} for H_2O (*Fig. 12*), with several peaks of asymmetrically substituted aromatic rings (1455, 1592 cm^{-1}) and peaks of the SO_3^- (615 and 1233 cm^{-1}) and NH_3^+ groups (1646 cm^{-1}).

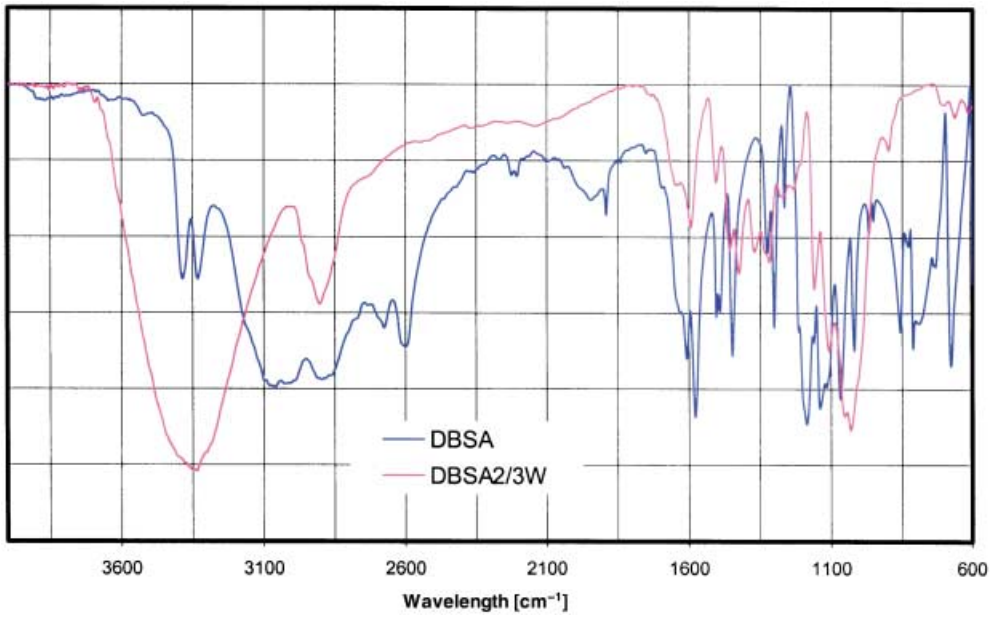

Fig. 12. *FT-IR Spectra, run by means of an FT-IR microscope, of DBSA⅔W* (pink) *and DBSA* (blue). The intensities of these spectra are normalized to facilitate comparison.

The FT-IR spectrum of DBSA is quite different from that of DBSA⅔W, as would be expected from their crystal structures. For example, the absence of the broad peak

assigned to H_2O at 3350 cm^{-1}, and the addition of two peaks instead assigned to NH_2 stretching, as well as a large peak at 3074 cm^{-1} for an asymmetrically substituted aromatic ring, and several smaller ones at 2674 and 2594 cm^{-1} for NH_3^+, 1182 and 1018 cm^{-1} for SO_3^- and 730 cm^{-1} for an NH_2 group. However, there are also a number of peaks at similar positions as a result of the same molecule's presence in both structures, such as the peaks at 2890, 1486, and 1447 cm^{-1} (CH stretch and bend), 1300 cm^{-1} (NH_2), and 1106 cm^{-1} (asymmetrically substituted aromatic ring).

The FT-IR spectra of the two polymorphs of DBSAHCl (*Fig. 13*) share a number of features, especially at lower wavelengths, although the overall shapes of the spectra are quite different. There are a number of peaks, which can be used to unequivocally identify each polymorph (*Table 7*).

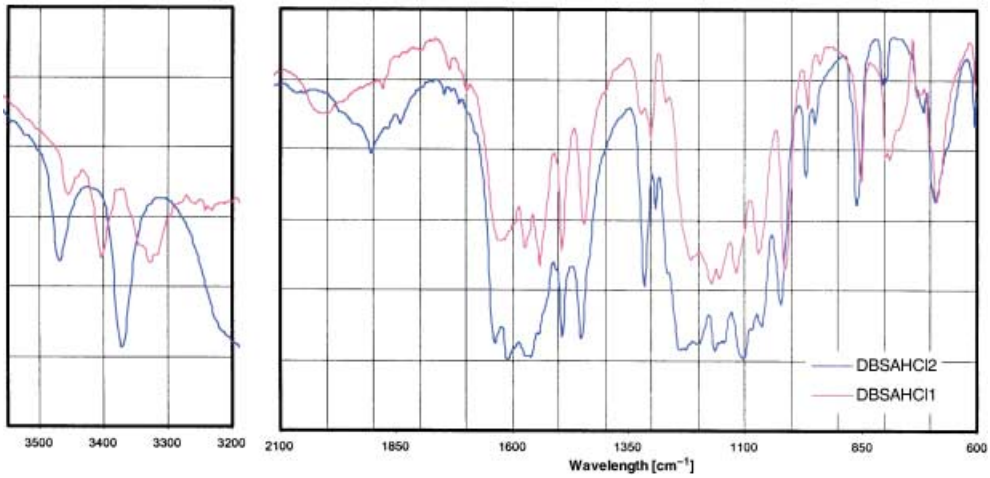

Fig. 13. *FT-IR Spectra of DBSAHCl1* (pink) *and DBSAHCl2* (blue)

Table 7. *Comparison of Peak Positions and Assignments* [25][26] *Characteristic of the DBSAHCl Polymorphs*

DBSAHCl1		DBSAHCl2	
$\tilde{\nu}/cm^{-1}$	Assignment	$\tilde{\nu}/cm^{-1}$	Assignment
	–	716.0	amino group
788.7	2 neighboring aromatic CH groups	796.9	2 neighboring aromatic CH groups
937.2	asymmetrically substituted aromatic	–	–
1005.1	asymmetrically substituted aromatic	1023.5	asymmetrically substituted aromatic
1991.6	R-SO_3	1904.4	R-SO_3
3321.1	CH stretch	–	–
3395.8	amino group	3371.1	amino group
3447.1	NH stretch	3468.7	NH stretch

Discussion. – We have described and characterized a number of crystal forms of 2,4-diaminobenzenesulfonic acid and of its hydrochloride salt. Originally described as an example of concomitant crystallization of polymorphs, this system apparently has

quite a rich crystal chemistry, some of which still remains to be investigated. For instance, we have not yet succeeded in isolating and characterizing the second form of DBSA reported variously by *Post* and *Hardtung* [2][3], *Groth* [1], and *Hunter* and *Sprung* [6]. The investigation reported here was considerably aided by the ability to rapidly screen crystalline samples on the single crystal diffractometer combined with optical microscopy employing a hot stage. These methods require minimal sample manipulation and provide a great deal of information; indeed once a crystal is mounted on the diffractometer and proves to be different from other samples, the full structure can be obtained in a matter of hours. The examination of many similarly appearing crystals by single-crystal analysis has previously been shown to reveal several multiple polymorphic structures [27]. It was this investigative approach that led to the discovery of a number of the forms.

The variety exhibited by this 'simple' system suggests re-investigating in greater detail a number of other systems for which the older literature indicates a richness of behavior. For example, investigations of the crystalline behavior of 2,5-diaminobenzenesulfonic acid and of the family of aminobenzenesulfonic acids are already underway with preliminary results indicating diversity similar to that reported here.

Experimental Part

Synthesis. DBSA was initially prepared (*Scheme 1*) by exposure of *meta*-nitroaniline (= 3-nitrobenzeneamine) to 4 times the quantity of vitriolic acid preheated to 175° in a melting tube. Application of 1 quantity of sulfuric acid at 160° for 1 h led to sulfonation to produce *2-amino-4-nitrobenzenesulfonic acid*.

The finely powdered 2-amino-4-nitrobenzenesulfonic acid was then reduced by treatment with Sn and conc. HCl soln. to produce colorless crystals of *2,4-diaminobenzenesulfonic acid*. This material was separated from the Sn by H_2S through evaporation from the liquid to yield two dimorphic modifications – a beige powder and orange-brown prisms.

We attempted to prepare 3,5-diaminobenzenesulfonic acid by sulfonation of benzene-1,3-diamine. A solid was precipitated from the soln. by the addition of AcOEt. The crystals were washed several times with AcOEt and then dried in a vacuum flask. The material was redissolved in a minimal amount of H_2O containing activated carbon. The soln. was then filtered to remove the activated carbon and crystals of the *2,4-diaminobenzenesulfonic acid* (DBSA) were obtained.

Thereafter, DBSA was obtained commercially from *Fluka* and used without further purification.

Single-Crystal X-ray Diffraction. All data were collected at r.t. by means of a *SMART-6000K* diffractometer and Mo$K\alpha$ radiation with a graphite monochromator. All atoms (including the H-atoms) were located from difference maps, confirming the zwitterionic nature of the molecules. The reported H-atoms were refined resulting in normal thermal parameters, and some shortening of the N–H bonds which were not corrected. The data were reduced by SAINT [28], solved with SHELXS [29], and then refined in SHELXTL [30]. Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the *Cambridge Crystallographic Data Centre* as deposit numbers CCDC 205715–205718. Copies of the data can be obtained, free of charge, on application to the CCDC, 12 Union Rd, Cambridge CB2 IEZ UK (fax: +44 (1223) 336 033; e-mail: deposit@ccdc.cam.ac.uk. Structure solution and refinement were carried out routinely. In all four structures the ratio of observed reflections to parameters was between 8.0 and 9.0.

Differential Scanning Calorimetry (DSC). All DSC measurements were performed using 'Rheometric Scientific Plus V v5.42' software on a *Polymer-Laboratories PL-DSC* differential-scanning calorimeter. The reported measurements were all run with a heating rate of 10°/min and an ambient cooling rate, in sealed Al pans.

Thermogravimetric Analysis (TGA). All measurements were run on a *Mettler-Toledo STAR* system at a heating rate of 10°/min under N_2 with a flow rate of 200 ml/min.

FT-IR Microscopy. FT-IR Microscopy was performed with a *Bruker* spectrometer, by means of an *Equinox 55* connected to an *IRScope II* with 'Opus' software.

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