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Alkyl Rearrangement of Derivatives of 2-Anilino-4,6-dialkoxy-1,3,5-triazines in the Solid- and Liquid-state

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2-Anilino-4,6-dimethoxy-1,3,5-triazine (13), 2-anilino-4,6-diethoxy-1,3,5-triazine (14), 2-(2′-nitoanilino) 4,6-dimethoxy-1,3,5-triazine (15) undergo alkyl rearrangement in the liquid-state, while 2-(4′-nitoanilino) 4,6-dimethoxy-1,3,5-triazine (16) undergoes methyl rearrangement in the solid-state. The crystal structure and thermal behavior of these compounds are described. 13 crystallizes in monoclinic *P*21/*c* space group, $a = 11.030(4)$, $b = 6.345(4)$, $c = 16.315(4)$ Å, $\beta = 90.76(3)°$. The calculated density for $Z = 4$ is 1.351 Mg/m^3. The number of unique reflections collected is 2092, and the final $R = 0.0643$ $[I > 2\sigma(I)]$. 14 crystallizes in triclinic *P*-1 space group, $a = 7.700(2)$, $b = 9.723(3)$, $c = 10.154(3)$ Å, $\alpha = 78.78(3)$, $\beta = 70.32(3)$, $\gamma = 73.67(3)°$. The calculated density for $Z = 2$ is 1.266 Mg/m^3. The number of unique reflections collected is 2401, and the final $R = 0.0561$ $[I > 2\sigma(I)]$. 15 crystallizes in monoclinic *P*21/*m* space group, $a = 11.020(3)$, $b = 6.600(2)$, $c = 8.409(3)$ Å, $\beta = 99.72(3)°$. The calculated density for $Z = 2$ is 1.527 Mg/m^3. The number of unique reflections collected is 1153, and the final $R = 0.0502$ $[I > 2\sigma(I)]$. 16 crystallizes in monoclinic *P*21/*c* space group, $a = 7.499(3)$, $b = 21.846(5)$, $c = 7.895(3)$ Å, $\beta = 115.42(3)°$. The calculated density for $Z = 4$ is 1.576 Mg/m^3. The number of unique reflections collected is 2036, and the final $R = 0.0757$ $[I > 2\sigma(I)]$.

Keywords: Rearrangement; Solid-state; Liquid-state; Thermal behavior

INTRODUCTION

Over 120 years ago, Hoffman and Olshausen [1] and later Klason [2] gathered evidence to prove that methyl esters of cyanuric acid and their thio derivatives undergo alkyl migration. In 1951, Schaefer [3] examined the thermal properties and the rearrangement reactions of 2,4-dialkoxy-6-amino-*s*-triazines in connection with other investigations of the chemistry of *s*-triazines derivatives. It was expected that rearrangement of the type shown in Scheme 1 would take place in elevated temperatures in view of the known rearrangement of trialkyl cyanurates to isocyanurates [1] (Hofmann, 1886), or the analogous rearrangement of aryl *N*-phenyliminobenzoates to *N*,*N*-diarylbenzamides [4], and other rearrangements induced by heat alone. It was found that the rearrangement reaction shown in Scheme 1 does occur if the amino group is not completely substituted, *i.e.*, if it bears at least one hydrogen atom.

There are several other known examples of solid-state methyl rearrangements, such as the

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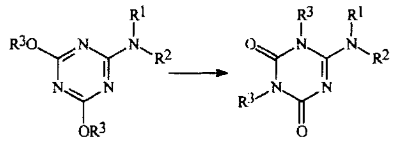
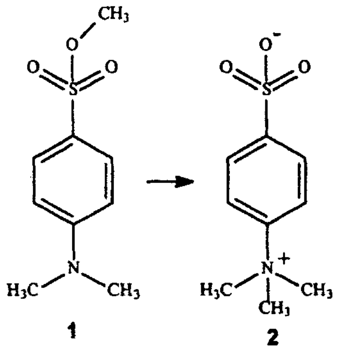
*Corresponding author.



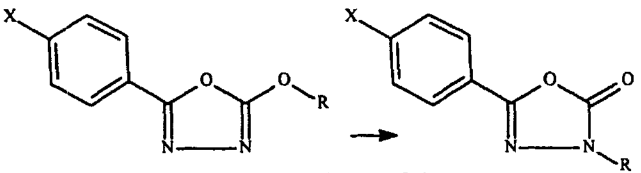
	R1	R2	R3
a	CH_3	C_6H_5	CH_3
b	H	H	C_4H_4
c	C_4H_4	H	CH_3
d	C_6H_5	H	CH_3

SCHEME 1

conversion of methyl *p*-dimethylaminobenzenesulfonate **1** into the zwitterionic product *p*-trimethylammoniobenzene-sulfonate **2**, first discovered by Kuhn and Ruelius [5], and later investigated by a few other groups [6a–g]. It was shown [6a] that the reaction is intermolecular and proceeds much faster in the solid-state than either in the melt or in solution. A second example of a methyl transfer in the solid-state is the Chapman-like rearrangement of iminoethers to *N*-alkylamides. Dessolin and Golfier [7] found that in some derivatives of 5-methoxy-2-aryl-1,3,4-oxadiazoles **3**, the rearrangement to the derivatives of 4-methyl-1,3,4-oxadiazole-5(4H)-ones **4** is unusually fast in the solid-state. It was shown that **3** undergoes intermolecular rearrangement in the solid-state faster than it does in the liquid-state. For example, for **3b**, $t_{1/2}$ is 7.85 minutes in the solid-state and 1.8 minutes in the melt; however, for **3d**, it is 0.8 minutes in the solid-state and 307 minutes in the melt.



1 **2**

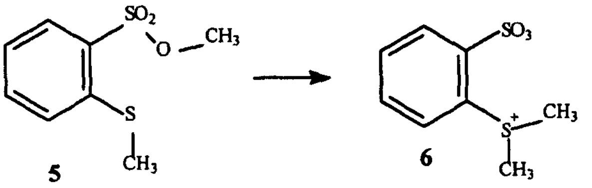


3 **4**

a: R=Me X=H
b: R=Me X=Cl
c: R=Me X=OMe
d: R=Me X=NO_2
e: R=CD_3 X=OCD_3

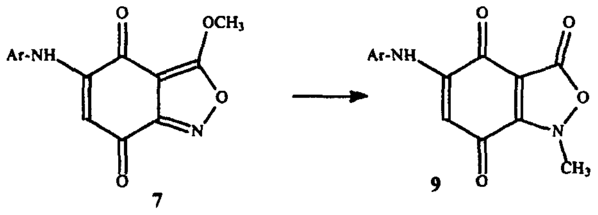
The mechanism of the solid-state reaction was the subject of two interesting publications [6b, 7b]. From the extended Hückel theory calculation, a two-step mechanism involving a molecular ion-pair intermediate was proposed [6b] for the conversion of **1** into **2**. A model system was used for studying the conversion of **3** into **4**. The transition state structure for the methyl exchange was localized with an analytical gradient, and the energies were calculated at the restricted Hartree-Fock level with a 3-21G basis set. These computations [7b] suggest that the starting point of the conversion is the formation of an anion and a cation, followed by the transfer of the methyl group between these ions and an adjacent molecule in the same plane. These substitutions are domino-like, propagating in chains.

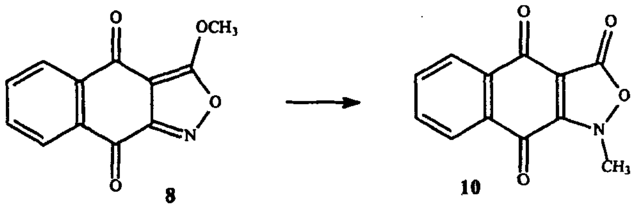
Four other examples of solid-state methyl migration are known [8a–d]. When tri- or tetraglycine methyl ester was heated at 400°C in the solid-state, a mixture of products was obtained and it was shown [8a–b] to include the methyl rearranged product, but no further work has been carried out on these systems. A thermally induced non-topochemical solid-state methyl rearrangement of methyl2-(methylthio) benzenesulfonate **5** to the zwitterionic 2-(dimethylsulfonium)benzenesulfonate **6** was observed [8c]. This rearrangement is known to proceed in solution by intermolecular methyl transfer. The crystal structure of **5** shows that the molecular packing is not conducive to intermolecular methyl transfer.



By fast-atom-bombardment mass spectroscopy on reaction products of mixed crystals composed of **5** and its deuteriomethylated species, and from the results obtained from the reaction rate study, it was concluded that the reaction proceeds not topochemically but rather at defects. A recent example [8d] is the thermal rearrangement of benzisoxazole **7** and naphthisoxazolequinones **8** to **9** and **10**, respectively.

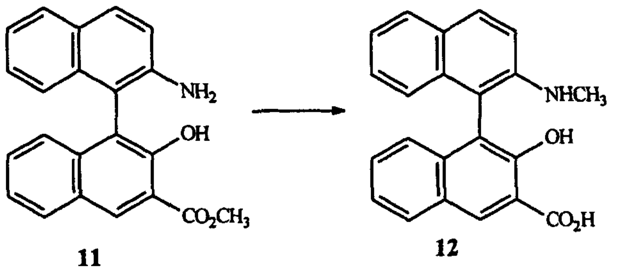
Following an extensive work on the rearrangement of *s*-triazines and its thio analogs [10] we have studied the solid- and liquid-state methyl rearrangement of methoxy- and thioxo-*s*-triazines [11]. It was found that topochemically controlled intermolecular methyl rearrangement in the solid-state takes place at lower temperatures (ca. 100°C) than that of solid-state non-topochemically controlled reaction (ca. 200°C), or in the liquid-state. Our interest in the compounds shown in Scheme 2 stems from the possibility that they may also undergo intermolecular rearrangement in the solid state. In some derivatives a nitro group was added as a synthon for hydrogen bonding in order to increase the melting point of the compound.

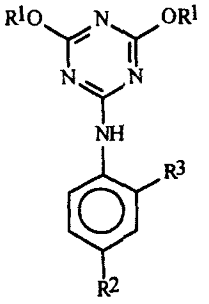




Binaphtyl derivative **11** undergoes solid-state rearrangement to **12** by a very interesting S_N2 pathway. By double isotopic labeling, it was proved [9] that the rearrangement is enantioselective.

The replacement of methyl groups by ethyl groups was done to examine the possibility of solid-state rearrangement of larger alkyl groups. The crystal structure determined by X-ray diffraction and the thermal behavior studied





13 R1=Me R2=R3=H
14 R1=Et R2=R3=H
15 R1=Me R2=H R3=NO2
16 R1=Me R2=NO2 R3=H

SCHEME 2

by differential scanning calorimeter of compounds **13**–**16** are presented.

RESULTS AND DISCUSSION

The Crystal Structures of 13–16

Although the crystal structure of **13** has already been published [12] we have repeated the data collection and crystal structure refinement. Crystallographic data for compounds **13**–**16** is given in Table I. Atomic coordinates, atomic displacement parameters, bond lengths and angles are given as supplementary materials. Atomic numbering of the molecular skeleton is shown in Scheme 3.

The packing arrangement of the molecules in all four compounds is determined by hydrogen bonding (see Figs. 1–4 and Tab. II). There are, however, differences between the strengths of these H-bonds. Strong H-bonds exist between the NH group as the donor and strong acceptors such as nitro group and nitrogen lone-pair electrons. Weaker H-bonds were found between methyl hydrogen atoms and nitro groups.

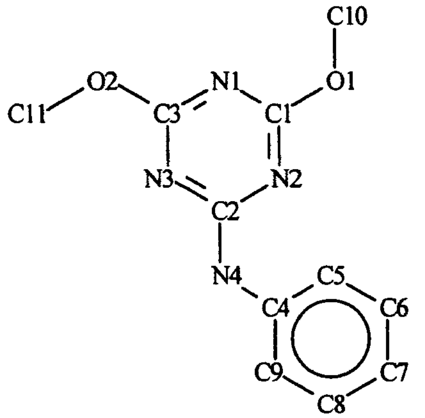
The molecules of **13** and **14** are packed in a hearing-bone fashion and molecules of **15** and **16** are packed in layers.

Comparison of bond lengths and bond angles of the triazine ring is given in Table III. Some geometrical parameters should be noted. The inner-ring bond angles at the C atoms are significantly larger (125.0(2)–128.8(3)°) than those at the N atoms (111.5(3)–(113.8(2)°). This finding is consistent with those found in other methoxy-*s*-triazines [13]. The opposite is observed when the methyl groups rearranged by migrating to the N atoms [14]. Steric repulsion plays an important role in determining the molecular geometry, especially with regard to bond angles. The phenyl ring, for example, causes an opening of the C(2)–N(4)–C(4) bond angle to 127.6(2)–132.5(4)°; it also responsible for the differences between the outer-ring bond angle at C(2), 113.1(4)–116.4(2)° at the less hindered side of the triazine (N(3)–C(2)–N(4)) to 118.6(2)–121.3(4)° at the more hindered side of the triazine (N(2)–C(2)–N(4)).

The conformation of the four molecules is largely determined by three torsion angles, two of which describe the rotation of the methoxy (and ethoxy) groups, and the third describes the rotation of the phenyl ring with respect to the triazine ring. The phenyl ring is practically co-planar with the triazine ring in the three methyl derivatives where the torsion angles C(2)–N(4)–C(4)–C(5) are 7.5, 0, 3.9° in **13**, **15** and **16** respectively. In the ethoxy derivative **14**, however, the torsion angle is 49.3°. The methoxy and the ethoxy groups are practically co-planar with the triazine ring (the range of the torsion angles about C(1)–O(1), and C(3)–O(2) bonds are 0–6.7°). It is interesting to note that the four compounds adopt the three possible conformations shown in Scheme 4, namely the Propeller (in **13** and **14**), the Butterfly (in **15**) and the Crown (in **16**). All three different conformations

TABLE I Crystal data and structure refinement for **13–16**

Identification code	**13**	**14**	**15**	**16**
Empirical formula	$C_{11}H_{12}N_4O_2$	$C_{13}H_{16}N_4O_2$	$C_{11}H_{11}N_5O_4$	$C_{11}H_{11}N_5O_4$
Formula weight	232.25	260.30	277.25	277.25
Temperature	293(2) K	293(2) K	293(2) K	200(1) K
Wavelength	0.71093 Å	0.71069 Å	0.71070 Å	0.71069 Å
Crystal system, space group	Monoclinic, *P*21/*c*	Triclinic, *P*-1	Monoclinic, *P*21/*m*	Monoclinic, *P*21/*c*
Unit cell dimensions	$a = 11.030(4)$Å $\alpha = 90.00$ (3)° $b = 6.345(4)$Å $\beta = 90.76$ (3)° $c = 16.315(4)$Å $\gamma = 90.00$ (3)°	$a = 7.700(2)$Å $\alpha = 78.78$ (3)° $b = 9.723(3)$Å $\beta = 70.32$ (3)° $c = 10.154(3)$Å $\gamma = 73.67$ (3)°	$a = 11.020(3)$Å $\alpha = 90°$ $b = 6.600(2)$Å $\beta = 99.72$ (3)° $c = 8.409(3)$Å $\gamma = 90°$	$a = 7.499(3)$Å $\alpha = 90°$ $b = 21.846(5)$Å $\beta = 115.42$ (3)° $c = 7.895(3)$Å $\gamma = 90°$
Volume	1141.7(9)Å^3	682.7(3)Å^3	602.8(3)Å^3	1168.2(7)Å^3
Z, Calculated density	4, 1.351 Mg/m^3	2, 1.266 Mg/m^3	2, 1.527 Mg/m^3	4, 1.576 Mg/m^3
Absorption coefficient	0.097 mm^{-1}	0.089 mm^{-1}	0.120 mm^{-1}	0.124 mm^{-1}
F (000)	488	276	288	576
Crystal size	0.25 × 0.15 × 0.08 mm	0.55 × 0.27 × 0.15 mm	0.42 × 0.30 × 0.07 mm	0.35 × 0.25 × 0.02 mm
Theta range for data collection	2.50 to 25.01°	2.14 to 25.01°	2.46 to 25.00°	3.00 to 25.00°
Limiting indices	$-13 < = h < = 13$, $0 < = k < = 7$, $0 < = l < = 19$	$-8 < = h < = 9$, $-11 < = k < = 11$, $0 < = l < = 12$	$-13 < = h < = 12$, $0 < = k < = 7$, $0 < = l < = 9$	$-8 < = h < = 8$, $0 < = k < = 25$, $0 < = l < = 9$
Reflections collected/unique	2092/2012 [*R*(int) = 0.0546]	2552/2401 [*R*(int) = 0.0211]	1232/1153 [*R*(int) = 0.0313]	2192/2036 [*R*(int) = 0.0671]
Completeness to	$\theta = 25.01$ 99.8%	$\theta = 25.01$ 99.9%	$\theta = 25.00$ 99.9%	$\theta = 25.00$ 99.0%
Absorption correction	None	None	None	None
Refinement method	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2
Data/restraints/parameters	2012/0/203	2401/0/237	1153/0/151	2036/0/225
Goodness-of-fit on F^2	0.923	1.190	1.182	1.123
Final *R* indices [$I > 2\sigma(I)$]	$R1 = 0.0643$, $wR2 = 0.1063$	$R1 = 0.0561$, $wR2 = 0.1310$	$R1 = 0.0502$, $wR2 = 0.1188$	$R1 = 0.0757$, $wR2 = 0.1556$
R indices (all data)	$R1 = 0.1868$, $wR2 = 0.1331$	$R1 = 0.0796$, $wR2 = 0.1379$	$R1 = 0.0740$, $wR2 = 0.1286$	$R1 = 0.1418$, $wR2 = 0.1709$
Extinction coefficient	0.0005(16)	0.010(3)	Not done	0.006(3)
Largest diff. peak and hole	0.166 and −0.148 e.Å^{-3}	0.176 and −0.157 e.Å^{-3}	0.290 and −0.223 e.Å^{-3}	0.345 and −0.361 e.Å^{-3}



SCHEME 3

are found in a single molecule of 1,3,5-trimethoxybenzene [15] (see Scheme 4).

The conformation of the methoxy groups affect the molecular shape, thus **15**, adopting the Butterfly conformation, has an equilateral shape while **16**, adopting the Crown conformation, has an extended shape. The conformation strongly affects the outer-ring bond angles at C(1) and C(3). The bond angle within the U shape formed by N–C–O–C atoms (for example N(2)–C(1)–O(1) in **13**) is always significantly larger (118.3(3)–119.3(3)°) than the outer bond angle at the same atom (112.6(2)–113.8(3)°) (for example N(1)–C(1)–O(1) in **13**).

Thermal Behavior

The thermal behavior of the four compounds (**13**–**16**) was examined by Differential Scanning Calorimetry (DSC) and the results are shown in Figure 5. The DSC thermographs of **13**–**15** are very similar; they consist of a single endotherm assigned to the melting of the relevant compound, followed by an exotherm assigned to the methyl (or ethyl) rearrangement that takes place in the liquid-state. The melting temperatures are 134, 111 and 168°C and the measured melting enthalpies are 35.7, 37.9 and 40.6 kJ/mole for **13**, **14** and **15** respectively. The rearrangements take place at 187, 255 and 192°C, and the measured enthalpies are −118.1, −89.9 and −95.1 kJ/mole, for **13**, **14** and **15** respectively. As a result of

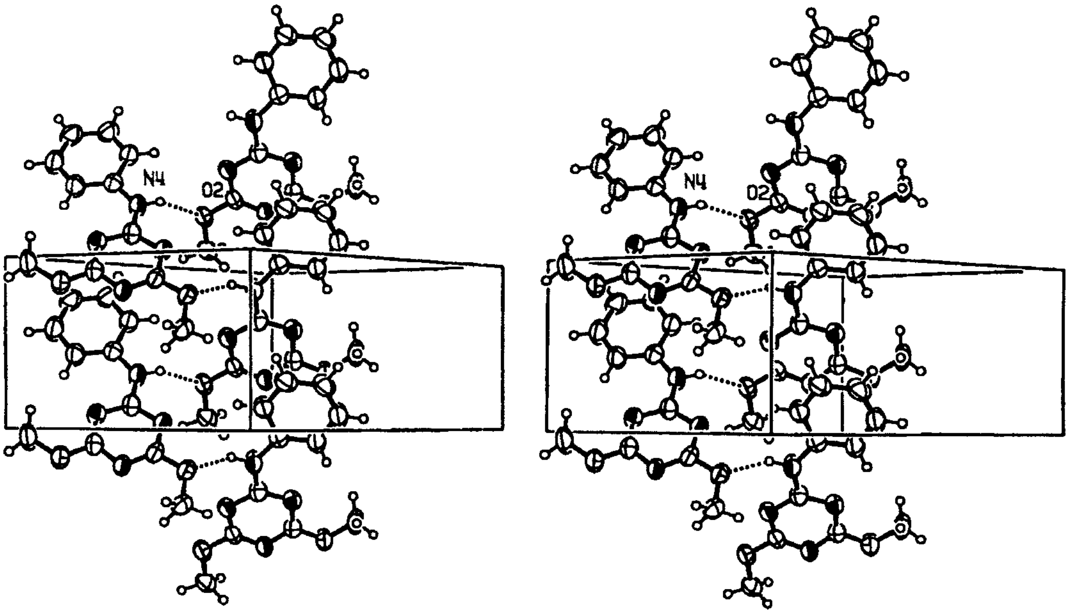


FIGURE 1 Stereo view of the crystal structure of 13.

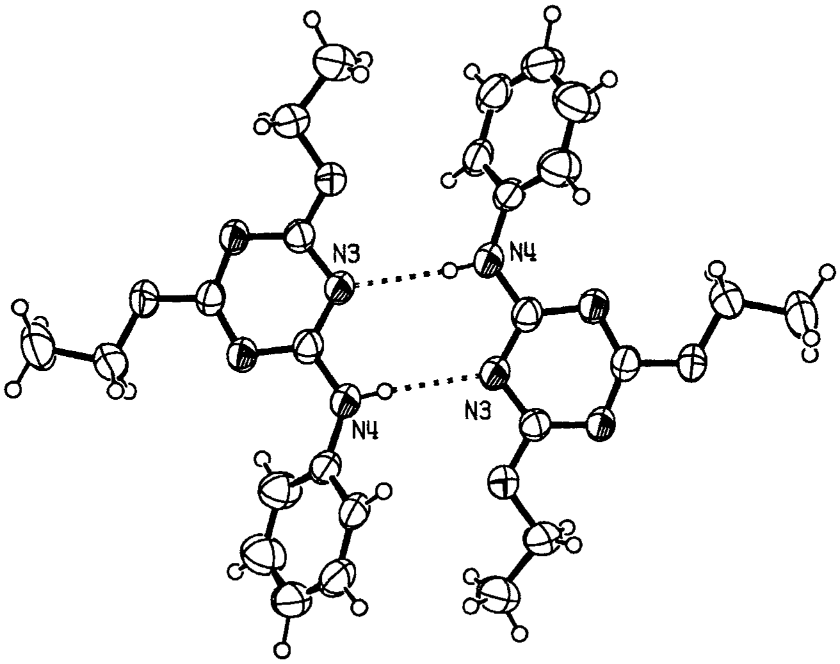


FIGURE 2 Dimers of **14**.

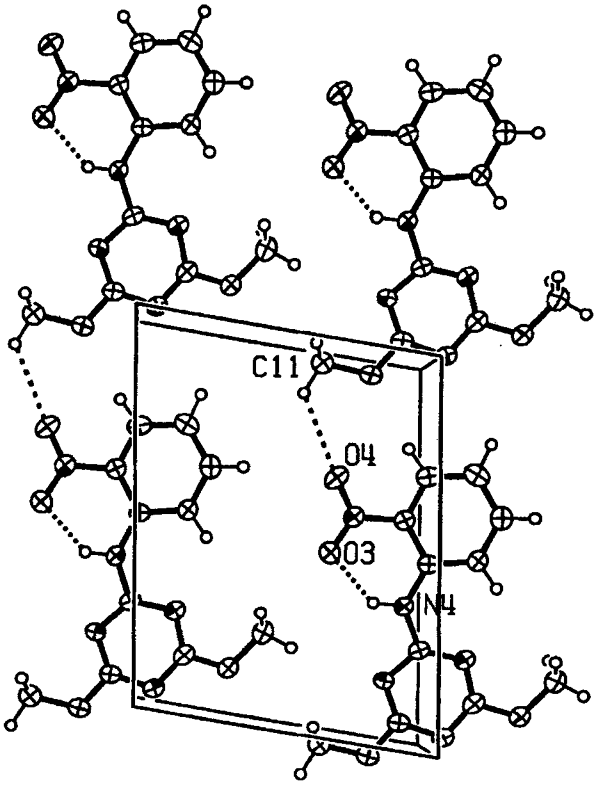


FIGURE 3 A layer of **15** showing the hydrogen bonds.

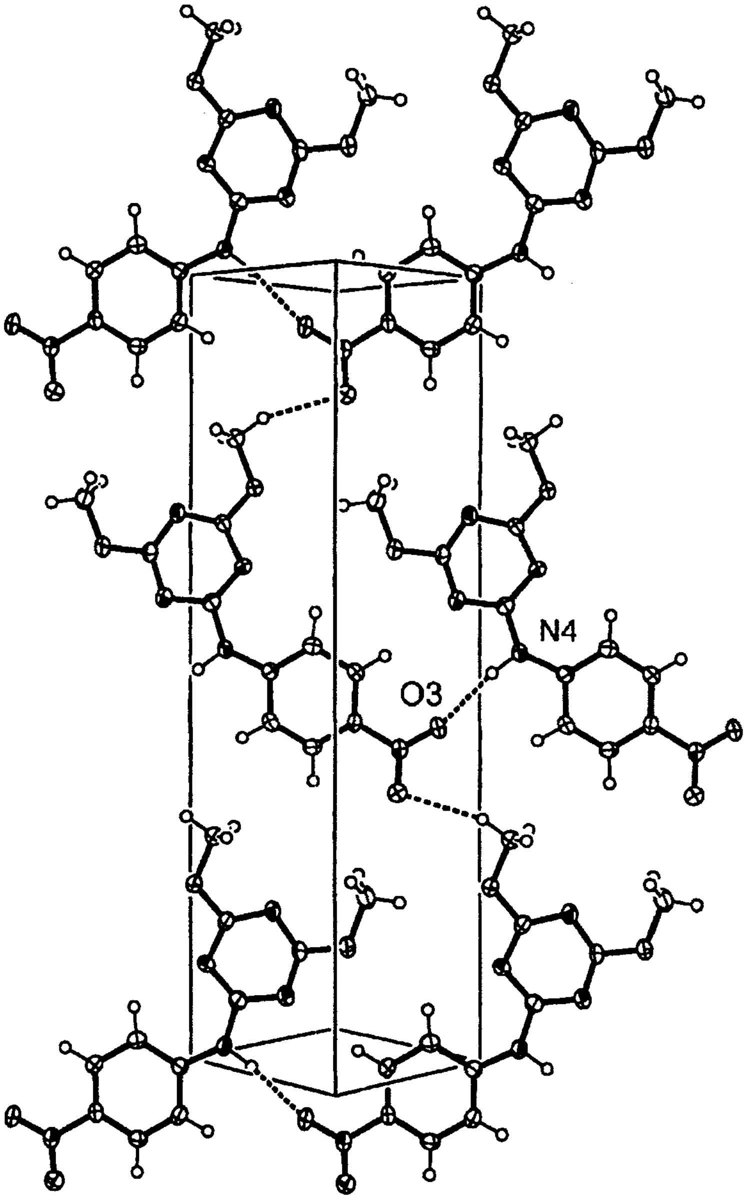


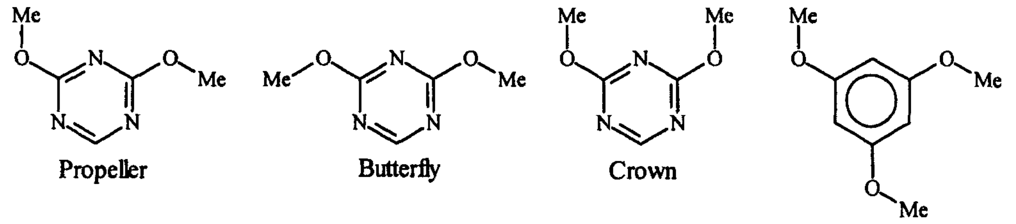
FIGURE 4 A layer of **16** showing the hydrogen bonds.

TABLE II Hydrogen bond geometry in **13–16**

Comp.	Donor(D)	Acceptor(A)	H-A (Å)	D-A (Å)	D-H-A (°)
13	N(4)-H	O(2)-Me	2.359	3.037	136.6
14	N(4)-H	N(3)	2.283	3.090	170.3
15	N(4)-H	O(3)-N-O(4)	1.900	2.632	138.2
15	H_2C-H(111)	O(4)-N-O(3)	2.601	3.324	127.6
16	N(4)-H	O(3)-N-O(4)	2.142	3.082	169.6
16	H_2C-H(101)	O(4)-N-O(3)	2.565	3.464	161.6

TABLE III Comparison of bond lengths and bond angles of the triazine moiety in **13–16**

	13	**14**	**15**	**16**
O(1)-C(1)	1.343(4)	1.342(3)	1.335(4)	1.335(5)
O(1)-C(10)	1.445(5)	1.438(3)	1.444(5)	1.458(6)
O(2)-C(3)	1.347(4)	1.327(3)	1.338(4)	1.340(5)
O(2)-C(11)	1.462(5)	1.448(3)	1.440(5)	1.446(6)
N(1)-C(1)	1.343(4)	1.324(3)	1.321(4)	1.330(6)
N(1)-C(3)	1.334(4)	1.328(3)	1.338(4)	1.327(6)
N(2)-C(1)	1.332(4)	1.315(3)	1.328(4)	1.322(6)
N(2)-C(2)	1.347(4)	1.354(3)	1.331(4)	1.339(6)
N(3)-C(3)	1.331(4)	1.322(3)	1.316(4)	1.316(6)
N(3)-C(2)	1.347(4)	1.339(3)	1.347(4)	1.355(6)
N(4)-C(2)	1.361(5)	1.341(3)	1.362(4)	1.352(6)
N(4)-C(4)	1.410(5)	1.409(3)	1.392(4)	1.398(6)
C(3)-N(1)-C(1)	111.5(3)	112.4(2)	111.9(3)	112.1(4)
C(1)-N(2)-C(2)	112.8(3)	113.1(2)	113.5(3)	112.8(4)
C(3)-N(3)-C(2)	112.3(3)	113.8(2)	113.0(3)	113.3(4)
C(2)-N(4)-C(4)	131.8(4)	127.6(2)	132.0(3)	132.5(4)
N(2)-C(1)-N(1)	127.9(4)	128.3(2)	127.9(3)	128.4(4)
N(2)-C(1)-O(1)	119.3(3)	119.1(2)	118.3(3)	113.2(4)
N(1)-C(1)-O(1)	112.7(4)	112.6(2)	113.8(3)	118.4(4)
N(3)-C(2)-N(2)	126.6(4)	125.0(2)	125.7(3)	125.6(4)
N(3)-C(2)-N(4)	114.6(4)	116.4(2)	113.8(3)	113.1(4)
N(2)-C(2)-N(4)	118.9(4)	118.6(2)	120.5(3)	121.3(4)
N(3)-C(3)-N(1)	128.8(3)	127.3(2)	128.1(3)	127.8(4)
N(3)-C(3)-O(2)	112.6(3)	113.8(2)	119.2(3)	113.4(4)
N(1)-C(3)-O(2)	118.6(4)	118.8(2)	112.7(3)	118.8(4)



SCHEME 4

the rearrangements, mixtures of products are obtained. The composition of the mixture were not fully analyzed; however, ^{1}H NMR spectra provide proofs that the mixture of compounds contains methoxy and methyl groups. The composition of the mixture of the rearrangement products of **16** was analyzed and the results are given below. Contrary to **13–15**, which undergo liquid-state rearrangement, **16** undergoes methyl rearrangement in the solid-state. The molecules are packed in layers (see Fig. 4); however, there are no close contacts between the reaction centers, nitrogen lone-pair electrons, and methyl groups of neighbor molecules as found in methoxy-s-triazines [11]. Therefore, solid-state methyl rearrangement can't be expected to be topochemically controlled. Nevertheless, rearrangement takes place at 207°C, with measured total enthalpy of $-75.3\,\mathrm{kJ/mole}$.

Three different products (shown in Scheme 5) have been analyzed by ^{1}H NMR and by single crystal structure determination. Their crystal structures will be published elsewhere.

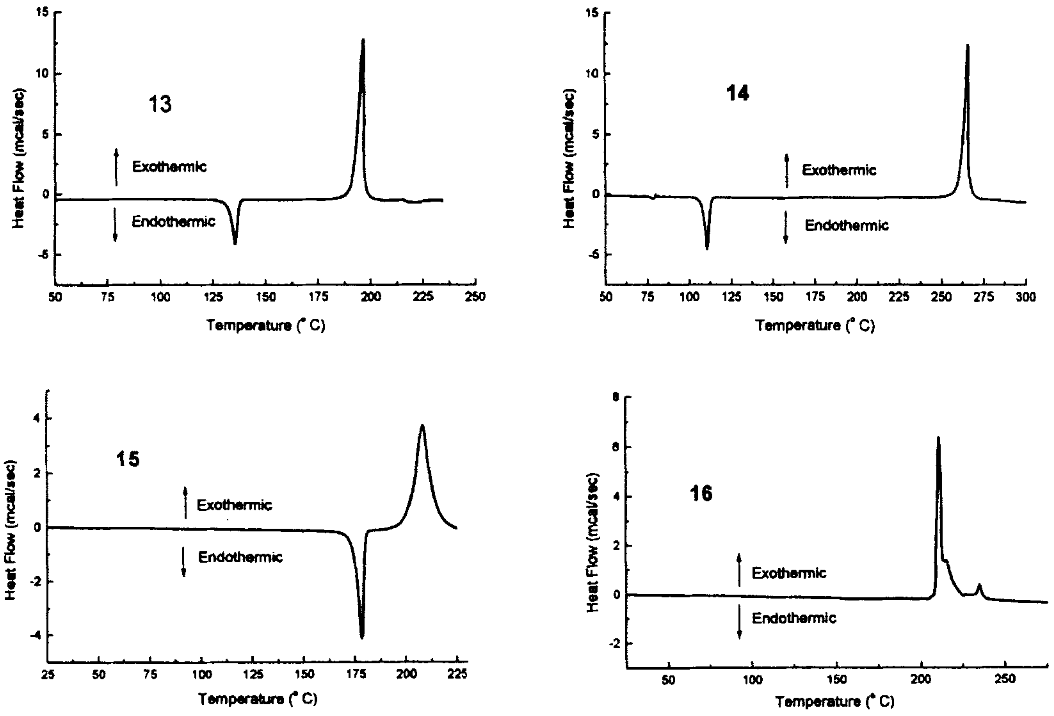
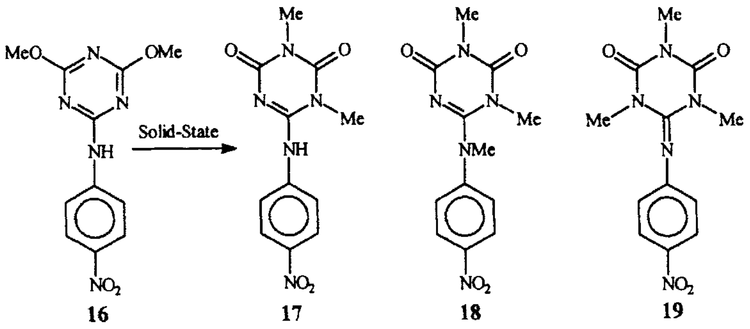


FIGURE 5 DSC thermographs of **13–16**, at a heating rate of 3°/min.



SCHEME 5

There are two methyl groups in the reacting compound (**16**) while there are three methyl groups in the products **18** and **19**. This is indicative of an intermolecular rearrangement. Also, these results may suggest that the reacting species is either a carbocation or a methyl radical. Only a few studies have been devoted to the thermal uncatalysed reaction mechanism of methyl transfer. In the case of 2-methoxypyridine Wiberg and coworkers [16] proposed a radical mechanism. The transfer of a methyl cation was proposed in the case of the triple rearrangement of 2,4,6-trimethoxy-1,3,5-triazine [6b]. Using 5-methoxy-2-aryl-1,3,4-oxadiazoles as models it was shown that the thermal rearrangement of imino-ether to *N*-alkylamides proceeds through a double ionic mechanism. *Ab initio* calculation [7b] shows that at the transition structure, the methyl fragment is planar and bearing a large positive charge which is indicative of a cation moiety.

A question arises from the different thermal behavior of the four compounds (**13**–**16**) in relation to the fact that **16** undergoes solid-state while **13**–**15** undergo liquid-state methyl (or ethyl) rearrangement. The ethyl rearrangement takes place at a higher temperature (255°C) than the methyl rearrangement (187, 192 and 207°C). The rearrangement will take place in the liquid-state whenever the melting temperature of the compound is low compared to the temperature where the rearrangement reaction starts (fission of the O–C bond). Whenever the packing forces are strong and the expected melting temperature is higher than the rearrangement temperature, the reaction will take place in the solid-state. A possible explanation for the expected higher melting temperature of **16** is concealed in the stronger inter-molecular hydrogen bonds. The only stronger hydrogen bond found in the other compounds is an intermolecular one observed in **15** (see Tab. II).

EXPERIMENTAL

Compounds **13** and **14** were synthesized according to the procedure of Dudley, Thrutson, Schaefer, 1951 [3d]. Suitable crystals for X-ray analysis were obtained by slow evaporation of methanol solutions of the compounds. Compounds **15** and **16** were prepared according to the procedure of Nohara, Sekiguchi, Matsui, 1970 [17]. Crystals suitable for X-ray analysis were obtained by slow evaporation of acetone solution. Thermal behaviors of 13–16 were investigated using a Differential Scanning Calorimeter DSC-PL from the Polymer Laboratory. NMR spectra were collected on a Bruker AC200 and AC400.

Relevant details of data collection and refinement of the crystal structures of **13**–**16** are collected in Table I. The crystal structures were solved by direct methods [18] and refined [18] using anisotropic displacement parameters for non-hydrogen atoms. All H atoms were located from difference Fourier maps and refined isotropically. Final **13**: ^{1}HNMR($CDCl_3$)δ3.98 (6H, s, —OCH_3), 7.13 (1H, *dd*), 7.33 (2H, *dd*), 7.57 (2H, *d*); **14**: ^{1}H NMR ($CDCl_3$) δ 1.36 (6H, *t*, —CH_3), 4.41 (4H, q, —OCH_2), 7.08 (1H, *dd*), 7.32 (2H, *dd*), 7.59 (2H, *d*); **15**: ^{1}H NMR ($CDCl_3$) δ 4.02 (6H, *s*, —OCH_3), 7.23 (1H, *t*), 7.64 (1H, *t*), 8.22 (1H, *d*), 8.86 (1H, *d*), 10.21 (1H, *s*, —NH); **16**: ^{1}HNMR (DMSO - d^6) δ 3.92 (6H, *s*, —OCH_3), 7.96 (2H, *d*), 8.18 (2H, *d*).

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References

[1] Hoffmann, A. W. and Olshausen, O. (1870). *Ber.*, **3**, 269.
[2] Klason, P. (1885). *J. Prakt. Chem.*, **33**, 116.
[3] (a) Thurston, J. T., Dudley, J. R., Kaiser, D. W., Hechenbleikner, I., Schaffer, F. C. and Holm-Hansen, D. (1951). *J. Am. Chem. Soc.*, **73**, 2981; (b) Kaiser, D. W., Thurston, J. T., Dudley, J. R., Schaffer, F. C., Hechenbleikner, I. and Holm-Hansen, D. (1951). *Ibid.*, **73**, 2984; (c) Dudley, J. R., Thurston, J. T., Schaffer, F. C., Holm-Hansen, D., Hull, C. J. and Adams, P. (1951). *Ibid.*, **73**, 2986; (d) Schaffer, F. C., Dudley, J. R. and Thurston, J. T. (1951). *J. Am. Chem. Soc.*, **73**, 2996.
[4] Chapman, A. W. (1925). *J. Chem. Soc.*, p. 1992; 1927, p. 1743.
[5] Kuhn, R. and Ruelius, H. W. (1950). *Chem. Ber.*, **83**, 420.
[6] (a) Sukenik, C. N., Bonapace, J. A. P., Mandel, N. S., Lau, P., Wood, G. and Bergman, R. G. (1977). *J. Am. Chem. Soc.*, **99**, 851; (b) Gavezzotti, A. and Simonetta, M. (1977). *Nouv. J. Chim.*, **22**, 69; (c) Dwarakanath, K. and Prasad, P. N. (1980). *J. Am. Chem. Soc.*, **102**, 4254; (d) Menger, F. M., Kaiserman, H. B. and Scotchie, L. J. (1984). *Tetrahedron Lett.*, **25**, 2311; (e) Prasad, P. N. (1987). *Organic Solid State Chemistry*, Edited by Desiraju, G. R., pp. 117–151; (f) Sarma, J. A. R. P. and Dunitz, J. D. (1990). *Acta Cryst.*, **B46**, 780; (g) Sarma, J. A. R. P. and Dunitz, J. D. (1990). *Acta Cryst.*, **B46**, 784.
[7] (a) Dessolin, M. and Golfier, M. (1986). *J. Chem. Soc., Chem. Commun.*, 38; (b) Dessolin, M., Eisenstein, O.,

Golfier, M., Prange, T. and Sautet, P. (1992). *J. Chem. Soc. Chem. Commun.*, 132.

[8] (a) Sluyterman, L. A. and Veenendaal, H. J. (1952). *Recuil*, 137; (b) Sluyterman, L. A. and Veenendaal, H. J. (1952). *Recuil*, 277; (c) Venugopalan, P., Venkatesan, K., Klausen, J., Novotny-Bregger, E., Leumann, C., Eschenmoser, A. and Dunitz, J. (1991). *Helvetica Chim. Acta*, **74**, 662; (d) Nartinez-Diaz, M. V., Rodriguez-Morgade, S., Schafer, W. and Torres, T. (1993). *Tetrahedron*, **49**, 2261.

[9] Smarina, M., Vyskoil, Š., Hanuš, V., Polášek, M., Langer, V., Chew, B. G. M., Zax, D. B., Verrier, K. H., Claxton, T. A. and Kocovsky, P. (1996). *J. Am. Chem. Soc.*, **118**, 487.

[10] (a) Paolini, L., Tosato, M. L. and Cignitti, M. (1968). *Heterocyclic Chem.*, **5**, 553; (b) Tosato, M. L. (1979). *J. Chem. Soc. Perkin Trans. II.*, 1371; (c) Tosato, M. L. (1982). *J. Chem. Soc. Perkin Trans. II.*, 1321; (d) Tosato, M. L. (1984). *J. Chem. Soc. Perkin Trans. II.*, 1593.

[11] (a) Kaftory, M. and Handelsman-Benory, E. (1994). *Molec. Cryst. Liq. Cryst.*, **240**, 241; (b) Handelsman-Benory, E., Botoshansky, M. and Kaftory, M. (1995). *Acta Cryst.*, **C51**, 2421; (c) Handelsman-Benory, E., Botoshansky, M., Greenberg, M., Shteiman, V. and Kaftory, M. (2000). *Tetrahedron*, **56**, 6887; (d) Greenberg, M., Shteiman, V. and Kaftory, M. (2000). *Acta Crystallogr.*, **C56**, 465.

[12] Glowka, M. L. and Iwanicka, I. (1991). *Acta Crystallogr.*, **C47**, 1036.

[13] Glowka, M. L. and Iwanicka, I. (1989). *Acta Crystallogr.*, **C45**, 1765.

[14] Taycher, H., Shteiman, V., Botoshansky, M. and Kaftory, M. (2000). *Acta Crystallogr.*, **C56**, 832.

[15] Stults, B. R. (1979). *Cryst. Struct. Commun.*, **8**, 401.

[16] Wiberg, K. B., Shryne, T. M. and Kintner, R. R. (1957). *J. Am. Chem. Soc.*, **79**, 3160.

[17] Nohara, N., Sekiguchi, S. and Matsui, K. (1970). *J. Heterocyclic Chem.*, 519.

[18] The following computer programs were used for crystal structure analysis: Program used to solve the crystal structures: *SHELXS86* (Sheldrick, 1990). Program used to refine the crystal structures: *SHELXL93* (Sheldrick, 1993). Molecular graphics: *ORTEP II* (Johnson, 1976); *TEXSAN* 1.6 *MSC*.