The structure of 2,3-dihydro-3-(2,4-dioxo-6-methylpyran-3-ylidene)-2-(2-nitrobenzyl)-1,4-benzothiazine and the problem of orthogonal interactions

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Abstract

The structure of the title compound has been determined. The compound crystallizes in the $P2_1/n$ space group with 4 molecules in the unit cell. The structure is consistent with previous conclusions based on NMR spectroscopy; moreover it provides new information about the conformation of the thiazine ring, the nature of the intramolecular hydrogen bond and the sulfur/nitro "orthogonal interaction". This last aspect has been examined through the use of DFT calculations on a simplified model system.

Keywords: Benzothiazine, nitro group, orthogonal interaction, MP2 calculations, crystal structure

Introduction

The taxonomy of weak interactions is a prerequisite to the establishment of a general theory that will allow us to deduce supramolecular properties from molecular ones. It is therefore important to make such a catalogue describing new examples of the known interactions and still more important to describe new interactions. Amongst these, one of the most exciting is the so-called "orthogonal interaction" (OI), because its geometry is different from most known weak interactions (WI) (see Scheme 1). In general WIs are lineal or slightly bent, like for instance, hydrogen bonds.[1] On the contrary, OIs correspond to approach angles close to 90º.[2]

Scheme 1. Weak (WI) and orthogonal (OI) interactions.

The reaction between *o*-aminothiophenol **1** and an α,β-unsaturated carbonyl compound derived from dehydroacetic acid can afford two compounds: the "normal" (in the sense of frequently obtained) seven-membered ring resulting from the attack to the terminal olefin carbon and the "inverted" six-membered ring resulting from the attack on the other carbon. Multinuclear NMR spectroscopy (solution and solid-state) was able to identify both isomers.[3] In the case of the *ortho*-nitrophenyl derivative **2**, both isomers **3** (normal) and **4** (inverted) have been isolated and identified (Scheme 2).[1] Concerning **4**, two structural problems remain, the configuration *E* or *Z* of the exocyclic CC bond (3-3') and the conformation of the *o*-nitrophenyl group. Crystals of **4** (in reference 1, compound **5h**) were grown and the structure solved.
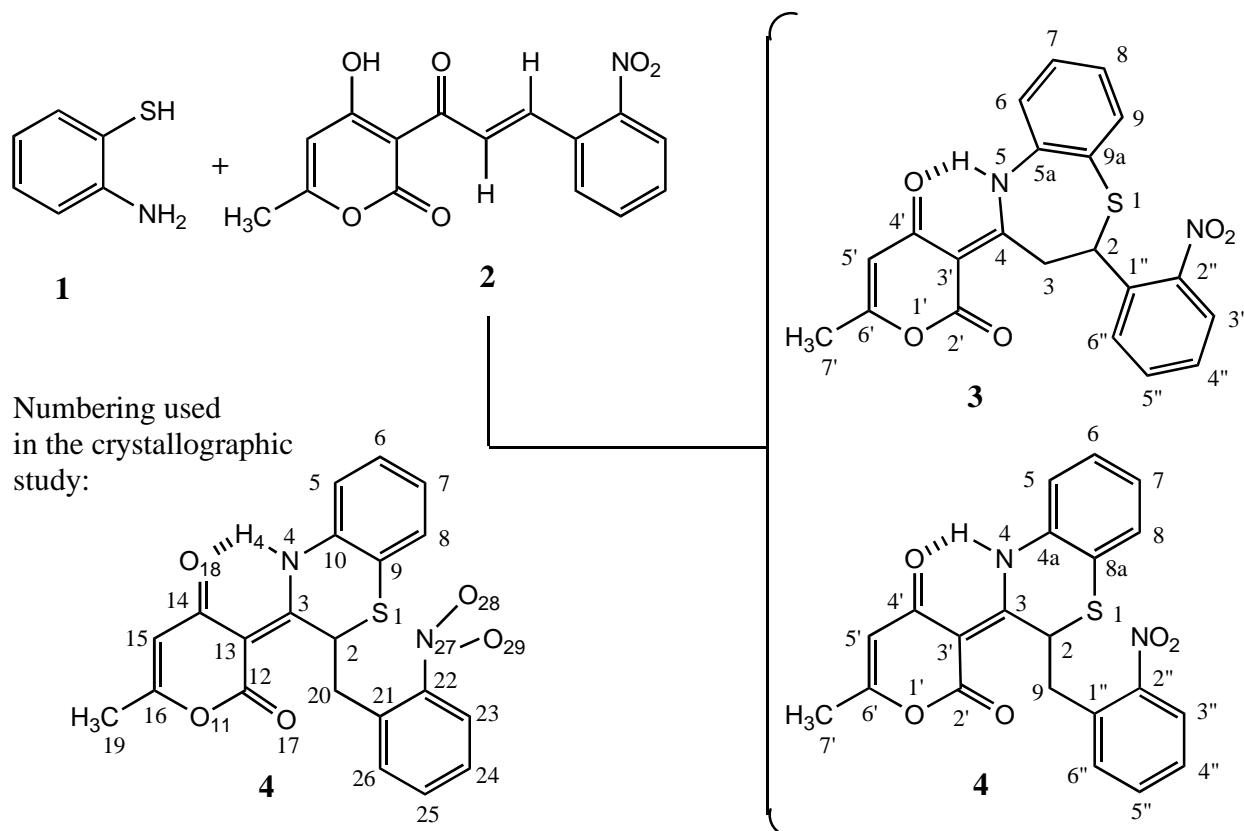
Scheme 2. Synthesis and numbering of **4.**

Results and Discussion

Two conclusions already reached by NMR were confirmed (from now on we will use the crystallographic numbering shown below): there is a double bond between C3 and C13 and there is a hydrogen bond (HB) between the N–H and one carbonyl oxygen atom. The crystallographic study (Table 1 and Figure 1) reveals that the oxygen atom involved in the HB is O18 (the vinyl ester oxygen and not the ester oxygen O17).

Table 1. Crystallographic data and structure refinement of compound **4**[a]

Empirical formula	$C_{21}H_{16}N_2O_5S$
M	408.42
Crystal system	monoclinic
Space group	$P2_1/n$
$a/\text{Å}$	7.303(1)
$b/\text{Å}$	19.430(3)
$c/\text{Å}$	13.289(2)
$\beta/°$	100.184(4)
$V_{cell}/\text{Å}^3$	1856.0(5)
Z	4
$D_c/\text{g cm}^{-3}$	1.462
T/K	293(2)
Absorption coefficient/mm^{-1}	0.212
F(000)	848
Crystal size/mm^{-1}	0.49 x 0.09 x 0.07
Theta range for data collection °	1.88 to 25.00
Index ranges	–8<=h<=8, –21<=k<=23, –14<=l<=15
Reflections collected	9644
Independent reflections	3268 (R_{int} = 0.1428)
Completeness to $\theta = 25.00°$	99.9%
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	3268 / 0 / 264
Goodness-of-fit on F^2	0.863
Final R indices [$I > 2\sigma(I)$]	$R1 = 0.0611$, $wR2 = 0.1304$
R indices (all data)	$R1 = 0.2367$, $wR2 = 0.1914$
Largest diff. peak and hole/e Å^{-3}	0.311 and –0.266

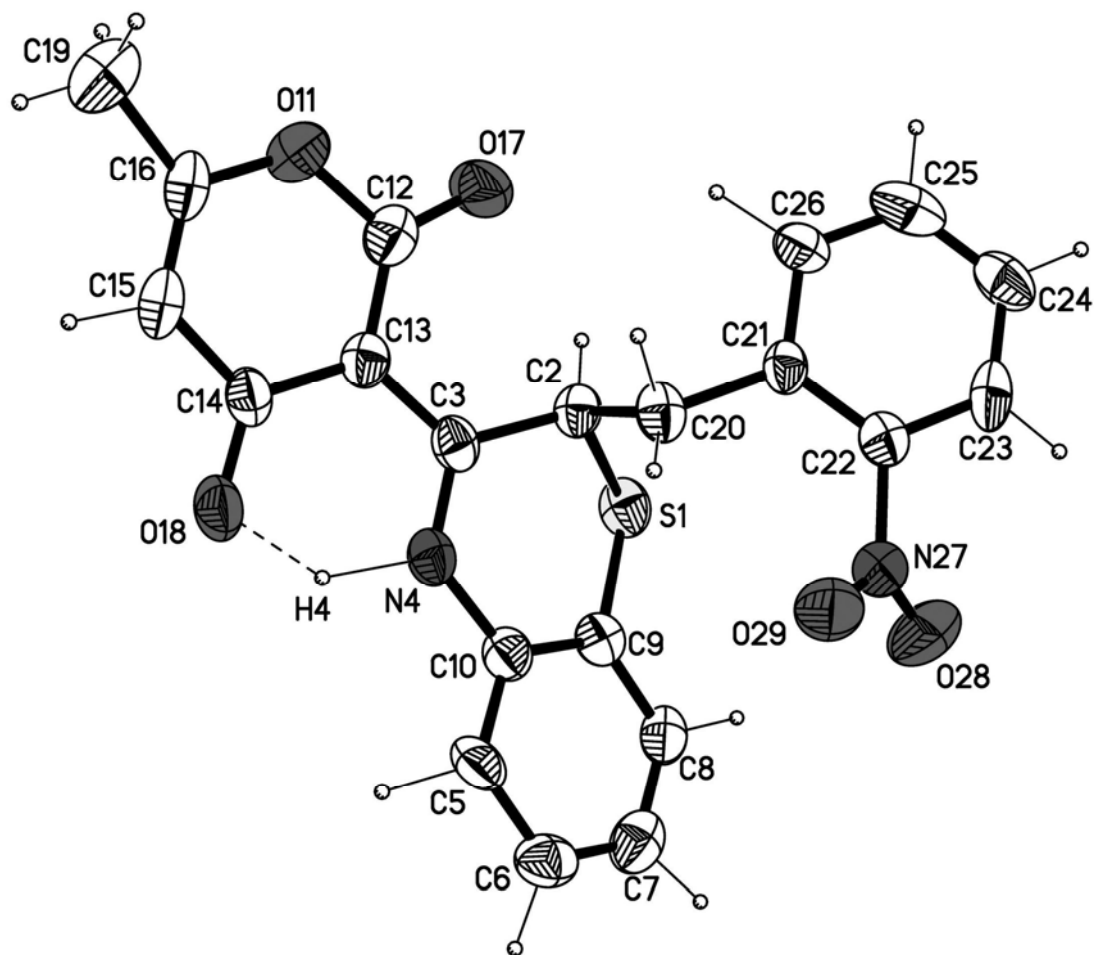[a] Full crystallographic data (CCDC 272084).

Figure 1. Crystal structure of compound **4**.

There has been a great interest in orthogonal interactions,[2,4] *i.e.* interactions where a group approaches another in a perpendicular way. We reported an example of interaction between an sp^2 nitrogen atom and a nitro group,[4] and Paulini, Müller and Diederich described many cases, including our result.[2] There is no example in the cited review of the interaction between an sulfur atom and a nitro group.[2] Therefore, if the interaction exists it should be quite weak. As Dunitz has pointed out "of the six polymorphs of 5-methyl-2-[(2-nitrophenyl)amino]-3-thiophene-carbonitrile[5] only in one of them (called YN) there is a molecular pair in which the sulfur of one molecule points at the nitrophenyl ring of its neighbor. It is, however, not the major intermolecular pair interaction in this polymorph, which is not the most stable one".[6]

We decided to examine if compound **4** could be an example of such interaction. We have shown in Figure 2 the fragment of the structure of **4** where the S/NO$_2$ interaction is visible and a model system based on a dimethyl sulfide-nitromethane complex.
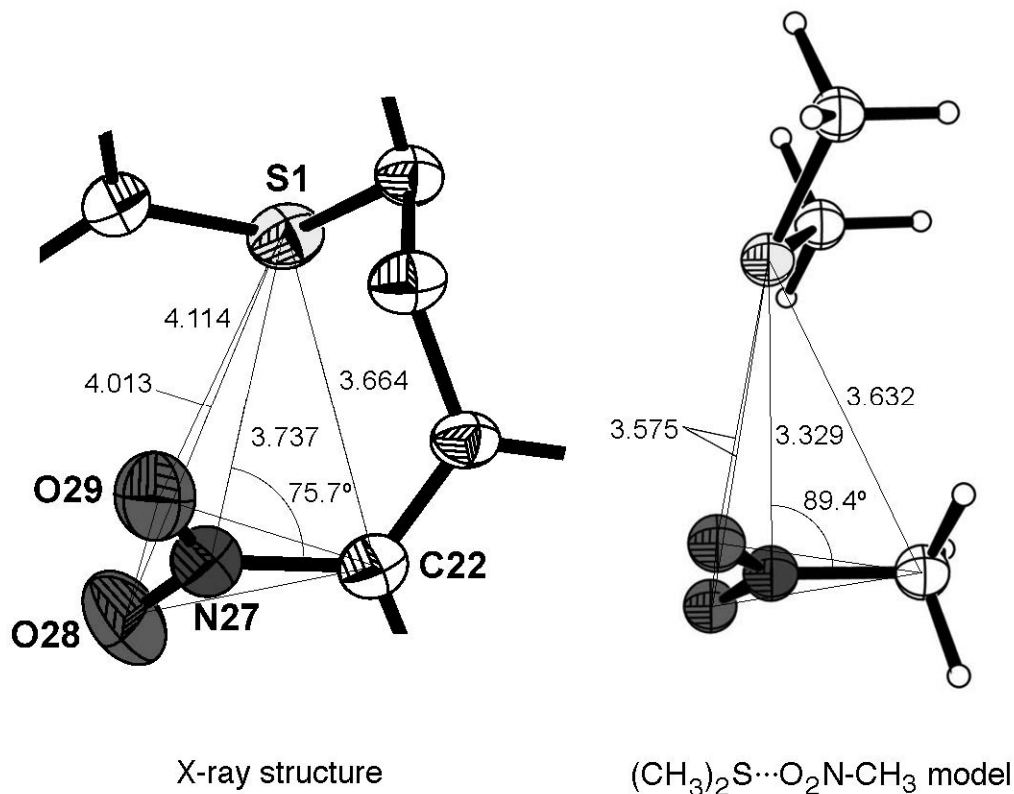
Figure 2. Possible S/NO$_2$ orthogonal interactions in the crystal structure of compound **4** and in a model compound.

Both nitro groups are planar (sum of angles about the nitrogen atom 360º). In the model compound only a C_s symmetry has been imposed. At the MP2/6-311++G** level the complex (– 721.715840 hartree) is 16.6 kJ mol^{-1} more stable than the sum of dimethylsulfide (–477.231066 hartree) and nitromethane (–244.478465 hartree) (no BSSE correction was carried out). When comparing the two situations of Figure 2, the one theoretically calculated is more favorable, more perpendicular and shorter, but the carbon chain in **4** limits the freedom to adopt a better geometry.

Conclusions

In conclusion, the possibility that a sulfur atom approaches, intra or intermolecularly, a nitro group perpendicular to the N atom in the plane defined by the O-O-N-C atoms should be considered when discussing conformation (intramolecular) and packing modes (intermolecular). The possibility of building up cages, similar to those of Fujita,[7] without using metal to make orthogonal corners, is a possibility that the interactions described in this paper offer.

Experimental Section

Computational details

The geometry of the model complex system and that of the monomers has been optimized at the MP2/6-311++G** computational level[8,9] using the Gaussian 03 facilities.[10] In the case of the model complex, the symmetry has been fixed as C_s. The symmetry plane goes through the CN bond of the CH_3NO_2 and the sulfur atom, bisecting the $(CH_3)_3S$ molecule.

Acknowledgments

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