

FULL PAPER

Molecular Mechanics: The Cross-conjugated Carbonyl Group in Heterocyclic Compounds. 2. Parameterisation (MM2) of the Adjacent C-O and C-N Bonds

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Abstract The definition, in a previous paper, of a new type of carbon atom (type 44) in the MM2 force field, i.e. when it is cross-conjugated, implies the reparameterisation of the bonds adjacent to the carbonyl bond. By means of a statistical study based on data issued from the Cambridge Structural Data System, we propose here new σ dipole moments and new stretching parameters for the C(44)-O(41) and C(44)-N(40) bonds included in heterocyclic compounds.

These stretching parameters, which are π -bond-order dependent, are quite satisfactory (mean of unsigned deviations: 0.023 Å) within limited π -bond-order ranges: 0.25 to 0.32 for the C-O bond, 0.37 to 0.53, for the C-N bond. As for the C(44)=O(7) bond the parameters are generally inappropriate for compounds in which both atoms connected to the type 44 carbon are heteroatoms.

The maximum deviation from the experimental bond length, for both bond types can reach ± 0.03 Å. Here also, part of the dispersion of the results could be attributed to the variation of the effective dielectric constant D from one crystal to another.

Keywords Molecular mechanics, Parameterisation, MM2, C-O Bond, C-N Bond, Heterocyclic molecules

Introduction

The intracyclic oxygen atom of α -pyrones or, more generally, of conjugated lactones is part of the delocalised π system. In MM2 nomenclature its type is 41. It participates in the π system by 2 electrons and is explicitly attributed a lone pair (type 20). In conjugated «lactams» the N atom is in a similar situation with 2 electrons also engaged in the π

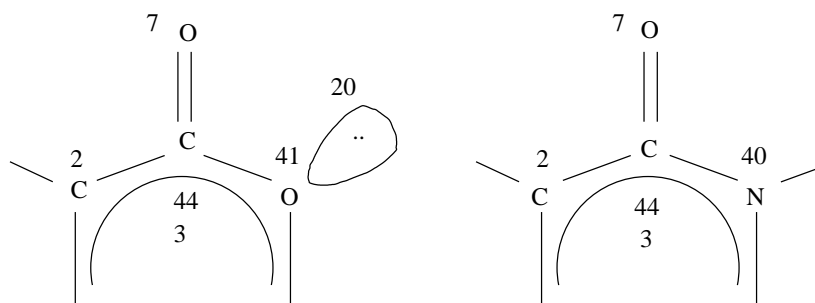
system (atom type 40). In both cases the C(3)-O(41) or C(3)-N(40) bonds adjacent to the carbonyl are not parameterised in the classical MM2 force field (Fig. 1).

Similarly, when the carbonyl is cross-conjugated deserving a special carbon type (type number: 44), parameters concerning the C(44)-O(41) and C(44)-N(40) bonds are missing [1].

In the present paper we propose, in conjunction with the parameterisation of the C(44)=O(7) bond, parameters for these adjacent bonds with emphasis on stretching parameters. Molecules cited in this paper are listed in Table 1.

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Figure 1 Type numbers of the atoms involved in the π system of conjugated lactones and lactams



Parameterisation of the C(44)-O(41) bond adjacent to a cross-conjugated carbonyl

The σ dipole moment of the C(44)-O(41) bond being reevaluated [1] and non- π -dependent parameters evaluated from already existing parameters in similar bonds, our effort was first applied to stretching parameters. Geometries of the molecules were found in the C.S.D.S. [2] in a similar way as in the preceding paper [1].

First estimation of l_2 , k_2 , TSLOPE and SSLOPE

The first estimation of the stretching parameters was performed in the usual way [1, 3]. The reference molecules were restricted here to α -pyrones (6-membered rings) and conjugated δ lactones (5-membered rings). Coumarin was added, thus giving 52 molecules containing 56 C(44)-O(41) bonds (compounds **1** to **52**). The plot of l_{exp} versus P_{exp} is reported in Fig 2. The equation of the corresponding best fit straight line is:

$$l_{exp} = 1.685 - 0.977 \times P_{exp} \quad (1)$$

with $r = -0.85386$

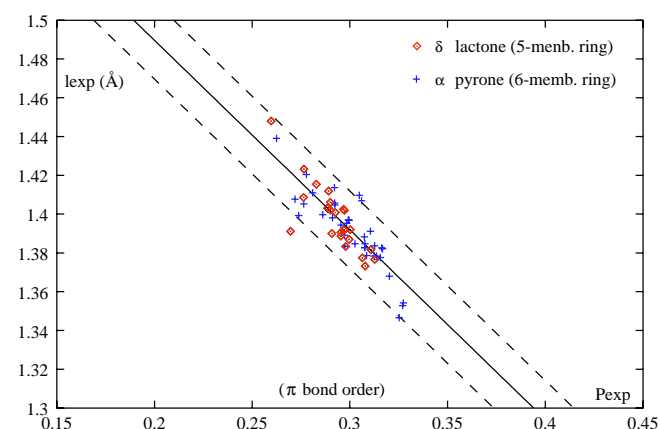


Figure 2 Plot of l_{exp} versus P_{exp} for the adjacent C(44)-O(41) bond in α -pyrones and δ -lactones

Its slope is steep and, around it, the dispersion of the dots rather high (± 0.02 Å). For the variation of the force constant with the π bond order, Badger's rule was used together with Allinger's parameters for atoms of the same period [4]:

$$k_{exp} \times (l_{exp} - 0.73)^3 = 1.865 \quad (2)$$

Combination of equations (1) and (2) leads to a theoretical expression of k_{exp} :

$$k_{exp}^{theor} = f(P_{exp}) \quad (3)$$

whose graph is reported in Fig 3 together with the dots corresponding to the couples (k_{exp}, P_{exp}) directly calculated from equation (2). Within the narrow domain of P_{exp} , a linear approximation is justified and the equation of the best fit straight line is:

$$k_{exp} = -2.02 + 28.32 \times P_{exp} \quad (4)$$

$r = 0.85127$

For the first estimations of the stretching parameters see Table 2.

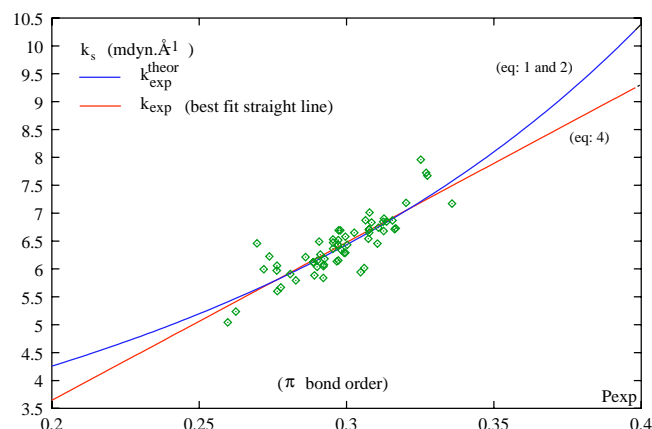


Figure 3 Plot of k_{exp} versus P_{exp} for the adjacent C(44)-O(41) bond in α -pyrones and δ -lactones

Table 1 List of the molecules cited in this work. The Refcode is mentioned when the geometry comes from the C.S.D.S. Compounds 53 to 55 are vinyl ester, 63 to 66 phthalimides or analogues and 67 to 94 conjugated lactams
Compounds 1 to 52 and 56 to 62 are α pyrones or δ lactones.

No.	Name	Refcode
1	Coumarin	COUMAR02
2	1-Oxa-azulen-2-one	OXAZUL
3	N-Acetyl-5,6-dihydrofuro(2,3-b)pyrid-2-one	AFURPO 10
4	4-Methoxy-6-(2,4-dihydroxy-6-methylphenyl)-2-pyrone	ALOAGL 10
5	5-Crotonoyl-4-methoxy-6-methyl-pyrone	BABNIB
6	7,8-Dihydro-4,7,7-trimethyl-2H,5H-pyrano(4,3-b)pyran-2,5-dione	BINTUN
7	6-Ethoxycarbonylamino-4-chloro-5-methyl thio carbonyl-2-oxo-3H-pyran	CATMOZ
8	Coarctatin dibromide	COARDB
9	5-Benzylidene-3-acetyl-oxolan-2,4-dione	COCVIZ
10	5Z-Carboxymethylene-3-chloro-4-methyl-2(5H)furanone	COMFRN
11	cis-Octa-2,4,6-triene-1,4,5,8-diolide	COTROL 10
12	3-Acetyl-4-hydroxy-6-phenyl-2-pyrone	CUZXUQ
13	Methyl alpha-(3-hydroxy-5-oxo-4-phenyl-2H-2-furylidene)-phenyl acetate	DADTEH
14	5-(trans-(Z)-beta,gamma-Epoxy-alpha-methoxy-cinnamylidene)-4-methoxy-furan-2(5H)-one	EPMCMF 10
15	3,3'-Diacyl-5,5'-bis(ethoxycarbonyl)-glaucyrene	ETGLAU 01
16	(-)-Dimethyl 1-acetyl-1,2,3,7-tetrahydro-7-oxopyrano(3,4-b)pyrrol-2,5-dicarboxylate	FAFYEQ
17	(E,E)-7-(2-Butenylidene)-1,7-dihydro-1-oxo-cyclopenta(c)pyran-4-carboxylic acid methyl ester	FIJHIP
18	3-Chloro-5,6-dihydro-4-methylphenylaminoangelicin	FIVRIL
19	3,9-Dimethyl-2,5,6,7-tetrahydrofuro (2,3-b)indolizin-2-one	GAKGOO
20	7-(Dimethylamino)-3,4-dihydro-N,N-dimethyl-5-oxo-2H,5H-pyrano(4,3-b) pyran-8-carboxamide	GEWBOZ
21	4-Chloro-5-dichloromethylene-2-furanone	GEXWUB
22	3-(1-(ethylamino)ethylidene)-6-methyl-3H-pyran-2,4-dione	HABNED
23	2-(beta-Hydroxyisopropyl)-2,3-dihydro-6,7-furano-coumarin	JECPUC
24	alpha-3(1-Phenyl-N-(dimethylcarboxamide)methylimine)-4,5-trimethylene-pyran-2-one	JEDYAS
25	4-Hydroxy-6-methyl-3-(3-dimethylaminoacryloyl)-2H-pyran-2-one	JIHJOZ
26	4,5,6,7-Tetrafluoro-8-methoxy-2H-cyclohepta (b) furan-2-one	JIJJAC
27	8-Benzyl-3-phenyl-2H-indeno (2,1-b) furan-2-one	JOPDIB
28	3-Benzoylamino-7,7-dimethyl-5-oxo-5,6,7,8-tetrahydrocoumarin	JUKZUK
29	3,4-Dichloro-2-(methoxycarbonyl(chloro)methylene)furan-4-one	JUNFUT
30	3,7-Dimethyl-1H,9H,10H-dipyran(4,3-b:3',4'-e)pyran-1,9-dione	KEMZUX
31	Acetylmelodorinol	KETDOC
32	trans-7,8-Dihydro-7-hydroxy-4-methoxy-7,8-dimethyl-2H,5H-pyrano(4,3-b) pyran-2-one (Benzene solvate)	KITRIO
33	2-Cyclohexenyl-4-cyclohexylidene-2-butenolide	KUPXIC
34	5-(p-Methoxyphenyl)-3-methoxy-penta-2,4-dien-4-olide	MXPEN0
35	3-(1-(Phenylamino)ethylidene)-6-methyl-2,4-dioxo-2,3-dihydro-4H-pyran	PAEXPY
36	5-(4-Acetoxy-6-methyl-2-pyran-3-yl)-3ethoxycarbonyl-1-phenylpyrazole	PANDEN
37	DL-4-Hydroxy-4H-furo(3,2-c)pyran-2(6H)-one	PATULO
38	3-Acetoacetyl-7-methyl-2H,5H-pyrano(4,3-b)pyran-2,5-dione	POCRAA
39	Reductiomycin	RDCTMC
40	N-(2-Phenyl-4Z,6E-2,4,6-heptatriene-4-olide-7-yl)morpholine	SAMGOC
41	4-Methoxy-6-(2-(2-furyl)ethenyl)pyran-2-one	SOWBOV
42	trans-Octa-2,4,6-triene-1,4,5,8-diolide	TOTROL 10
43	2,6-Dimethyl-5H-furo(3,2-b)pyran-5-one	VASDOI
44	2,7-Dimethyl-5H-furo(3,2-b)pyran-5-one	VASDUO
45	3-Diphenylmethylene-7-phenyl-9-oxabicyclo(4,3,0)non-1,4,6-trien-8-one	VOBRUZ
46	7-Methyl-7-methoxy-5-phenyl-oxatricyclo(6,3,0,0)underca-1,5-dien-4-one	VOCREK

Table 1 (continued)

No.	Name	Refcode
47	(4Z,6Z)-6-Acetyl-7-hydroxy-2,4,6-octatriene-4-olide	VOXGOE
48	9-Hydroxy-3-methyl-2H-naphto(2,3-b)pyran-2,5,10-trione	VUTDAP
49	3-(5-Chloro-2-benzoxazolyl)-7-diethylamino-2H-1benzopyran-2-one	VUWZUI
50	3-Acetyl-6-methyl-2H-pyrano(2,3-b)indolizin-2-one	WANPAC
51	alpha Pyrone	WIKCAU
52	Methyl-4,5dichloro-3-methyl-2-oxo-2H-pyran-6-carboxylate	YABYIJ
53	Dimethyl(3,3,4,4,5,5-hexamethyl-1E,2E-cyclopentanediyliidene)diacetate	HECBIA
54	Dimethyl-p-phenylene-diacrylate	PPDACR
55	Dimethyl 4,4-bis(ethoxycarbonyl)-1,2-cyclopentanediyliidenediacetate	ZEXSAW
56	alpha-Aminomethylene-glutaconic anhydride	AMYGLA
57	alpha,alpha'-Dibenzoylsuccinic acid bis (enol-lactone)	BZSCLC
58	7-Methyl-coumarin	DAXBUZ
59	(1) Benzopyrano(4,3-c)(1)benzopyran-5,11-dione	DAVVIF
60	3,5,8-Trimethyl-7-oxo-azuleno(6,5-b)furanone	CALLIK
61	Furo(2,3-h)coumarin	FUCOUN
62	Gnidicoumarin	GNIDOC 20
63	Phthalimide	PHALIM 01
64	N-Phenyl-phthalimide	ZZZAWJ 10
65	(2,4,6-Trimethylphenyl)-phthalimide	COMGOA
66	Naphthaloimide	NAPOIM
67	1-Benzyl-5-ethyl-1,2,5,6-tetrahydro-2-oxo-4-pyridine-acetic acid	BEPYAC
68	4-Bromo-1-methyl-3,5-diphenyl-2-pyridone	CANRAK
69	(5R,6S,11R)-Sophocarpine monohydrate	EPSOPH
70	1-Formyl-8-methoxy-3-methyl-5,6-dihydrobenz(f)-isoquinolin-2(3H)-one	JAMNOA
71	Cerpegin	JEGVOG
72	6-(2,4-Dimethylimidazol-1-yl)-8-methyl-2(1H)-quinoline	KAGYUM
73	Perfragilin B	KUNKUZ
74	Mimosamycin	MIMOSA 10
75	N-n-Butyl-3-hydroxy-2(1H)-pyridone	SABKEL
76	1,2,3,3,8-Pentamethyl-5-trifluoromethyl-2,3-dihydro-1H-pyrrolo(2,3-g)quinolin-7(8H)-one	VIGXAK
77	11-Hydroxy-6H-indolo(3,2,1-de)(1,5)naphthyridin-6-one monohydrate	AMARRN
78	2-(Methoxycarbonyl)canthin-6-one	DUTTOB 10
79	11-o-Bromobenzoyl-canthin-6-one	FAWLAQ
80	(-)-1,2,3,4,5,6-Hexahydro-3-methyl-1,5-methano-8H-pyrido(1,2-a)(1,5)diazocin-8-one	FITPON
81	2,5,6,7,8,9-Hexahydro-3,4-dimethyl-2-phenyl-1H-cyclohepta(c)pyridin-1-one	GIPCAJ
82	Methyl 3-methoxycarbonyl-1,2,3,5-tetrahydro-8-hydroxy-5-oxoindolizin-6-yl propanoate	SAFRUM
83	8-Benzoyl-1-methyl-7-methoxycarbonylimidazo(1,2-a)pyridin-5-one	SOWJIX
84	2,5,6-Trimethyl-9-methoxy-4H-pyrrolo-3,2,1-ij)quinolin-4-one	VIFCUI
85	Anagyrine	VOFDEZ
86	3,6-Diphenyl-1-methylquinoline	VORXAB
87	Picrasidine	YECYUA
88	7-Chloro-8-methyl-2(1H)-quinolinone	BAWVAW
89	8-Acetoxy-2-quinolone	BIMSIZ
90	4-Hydroxy-2-pyridone	CAXKOB
91	5-Chloro-2-pyridone	CLPYRO
92	2-Quinolone	HXQUIO 01
93	3-Benzoyl-2-phenyl-6(1H)-pyridone	PEXLAF
94	2-Pyridone	PYRIDO 04

Table 2 First estimation of the stretching parameters for the C(44)-O(41) bond

Atom types	k_2 (mdyn·Å ⁻¹)	l_2 (Å)	σ bond dipole moment (D)	SSLOPE (mdyn·Å ⁻¹)	TSLOPE (Å)
44 41	26.31	0.708	1.79	28.32	0.977

Refinement of the stretching parameters for the C(44)-O(41) bond

For the refinement of the estimated parameters, the usual strategy was used [1] but some modifications had to be made. The present bond is part of a ring (as is the C(44)-N(40) bond), so, its calculated length is dependent on its own parameters but also on the accuracy of the parameters related to the other parts of the ring. In the process of refinement, during the optimisation step, if we let the heavy atoms move, there would be a risk of over-correction of the C(44)-O(41) bond parameters to improve the geometry in other regions of the ring. In other terms, all the parameters involved in the ring are interdependent.

Several attempts were made using the rough values reported above and different types of constraint in the geometry optimisation phases. Most of them failed (poor values of α , β , r and δ), but it was possible to draw some lessons from them:

- necessity to look for a value of l_2 far from the first estimation

- necessity to modify k_2 and SSLOPE in relation to the evolution of l_2
- necessity to modify the bending parameters around the O(41) atom in conjunction with the refinement of the stretching parameters

- abandon of Badger's rule
- necessity to introduce some geometric constraints during the optimisation phase.

Around the intracyclic O(41) atom, there are 3 bonds: C(44)-O(41), O(41)-C(2) and O(41)-Lp(20). In MM2, the only way to fix some geometrical parameters (dihedral angles excluded) is to fix the cartesian coordinates of certain atoms. So, it was chosen to freeze, in their crystalline positions, all the heavy atoms but the O(41) and its lone pair. Thus, three bond lengths and seven bond angles are free to change in the course of optimisation (Fig 4).

Concerning the dihedral angles, care was taken to fix the O(7)=C(44)-O(41)-C(2) angle at its value in the crystal to prevent the relaxation of the molecule by an out-of-plane movement of O(41). In this context, the parameters to be refined will be dependent on the stretching parameters of the O(41)-C(2) and O(41)-Lp(20) bonds (which are known and

Table 3 First choice of auxiliary parameters (stretching and bending) necessary for the determination of the stretching parameters of the adjacent C(44)-O(41) bond

Topology	Atom types	Origin	starting values	
C-O	44-41		unknown	
C=O	44-7	[1]	parameters previously determined	
O-Lp	41-20	(MM2(91))	resident parameters	
O-C	41-2	(MM2(91))	resident parameters	
C-C	2-44	(2-3) (MM2(91))	resident parameters	
			k_θ (mdyn·Å·rad ⁻²)	Θ_{ijk} (°)
O-C-O	7-44-41	(7-3-6)	0.80	122.0
C-O-Lp	44-41-20	(2-41-20)	0.35	122.2
C-O-C	44-41-2	(2-41-2)	0.87	113.95
C-C-O	2-44-41	(2-3-6)	0.70	124.3
O-C-C	7-44-2	(7-3-2)	0.46	123.0
C-C-C	44-2-2	(3-2-2)	0.6	114.6
Lp-O-C	20-41-2	(MM2(91))	resident parameters	
O-C-C	41-2-2	(MM2(91))	resident parameters	
	41-2-1	(MM2(91))	resident parameters	

Table 4 Values adopted for the torsional parameters involving the C(44) atom along the optimisation process in the determination of the stretching parameters of the C(44)-O(41) bond

Topology	Atom types	V ₁	V ₂	V ₃
C-C-C-O	1-2-44-7	2.75	15.00	0.00
C-O-C-C	1-41-44-2	0.00	9.20	0.00
C-O-C-O	1-41-44-7	-1.66	8.98	0.00
C-O-C-O	2-41-44-7	0.00	11.10	0.00
C-C-O-C	2-44-41-2	0.50	11.10	0.00
C-C-O-Lp	2-44-41-20	0.00	0.00	0.25
O-C-C-H	41-44-2-5	0.00	11.10	0.00
O-C-C-C	41-44-2-1	0.00	11.10	0.00
O-C-C-C	41-44-2-2	0.50	11.10	0.00
C-C-C-C	44-2-2-1	0.00	15.00	0.00
C-C-C-H	44-2-1-5	0.00	0.00	0.20
C-C-C-C	44-2-2-2	0.00	15.00	0.00
C-C-C-H	44-2-2-5	0.00	15.00	0.00
C-O-C-H	44-41-1-5	0.00	0.00	-0.132
C-O-C-H	44-41-2-2	0.00	11.10	0.00
O-C-C-H	7-44-2-5	3.00	11.10	0.00
O-C-C-C	7-44-2-2	1.53	6.50	0.83
O-C-O-Lp	7-44-41-20	0.00	0.00	0.00

resident in the program) and also on the bending parameters which were known or were adopted by analogy, at least at the beginning of the refinement. They are presented in Tables 3 and 4.

For a preliminary estimation of k_2 ($k_2 = k_1 + \text{SSLOPE}$), Badger's rule was rejected and a simulation adapted to force constants performed in the following way. On the whole set of reference molecules, for $l_2 = 0.708$ and $\text{TSLOPE} = 0.977$ (see above) a series of optimisations was run, with geometries partially fixed and progressively changing values of k_2 . Simultaneously, for each value of k_2 , for the whole set of molecules, the sum of the ($l_{\text{cal}} - l_{\text{exp}}$) deviations was calculated. Figure 5 represents this sum versus k_2 . A minimum was found for $k_2 = 19.31 \text{ md.}\text{\AA}^{-1}$. This was the best starting value, i.e. for starting values of l_2 and TSLOPE . Any further modification of these last two parameters would, of course,

imply a reestimation of k_2 and so on. We proceeded in the same way to improve the bending parameters whose first values are collected in Table 3.

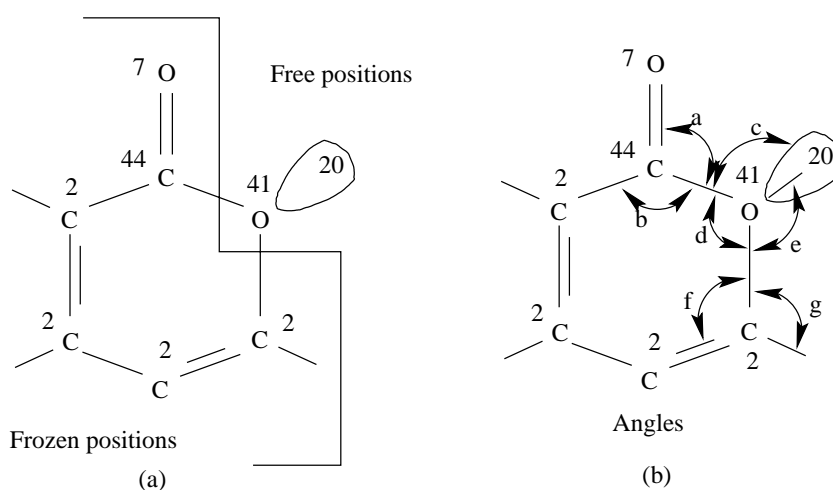
At that point, in order to extend the bond length domain, molecules containing a shorter C-O bond adjacent to a cross-conjugated carbonyl were looked for. Three vinyl esters were introduced (compounds **53** to **55**) containing altogether six C-O bonds.

By a process similar that described in a previous paper [1], for the last values of k_2 and SSLOPE , the best parameters (i.e. the parameters which satisfy the α , β , r and δ criteria) were found to be:

$$l_2 = 0.350 \text{\AA} \quad \text{TSLOPE} = 1.474 \text{\AA}$$

Figure 6 illustrates this. An attempt to reevaluate k_2 to put it in accordance with these new values of l_2 and TSLOPE showed that $k_2 = 19.81 \text{ md.}\text{\AA}^{-1}$ was still suitable (see Fig 7).

Figure 4 [a] Frozen and free atoms in the optimisation process. [b] Angles which consequently are allowed to distort in the optimisation process



To test these values of the stretching parameters and possibly improve them once again, 20 molecules were selected whose geometries were fully optimised. It appeared from the results that the main discrepancies involved the bending parameters which, because of the cyclic character of the molecules, entail some errors in the bond lengths.

The "natural" angles involving a carbon atom of type 44 were thus improved. To do so, molecules containing the α -pyrone ring or analogues were selected from the C.S.D.S. and, from 558 observations, slightly different new bending parameters were adopted (see Table 5). With these new bending parameters, two approaches were followed:

- The 20 test molecules were optimised using the new bending parameters and the former stretching parameters.

- Using the new bending parameters, an attempt was made to improve the stretching parameters once again.

The second option led to a new set of parameters which, tested on the 20 test molecules, did not improve the results. The first option, on the contrary, showed a systematic error on the C(44)-O(41) natural bond length and so l_2 was increased by 0.012Å which substantially improved the results. Finally, we propose for this bond, the following stretching parameters (see table 6) and for the bending parameters, those gathered in Table 5.

Table 5 New bending parameters (involving the C type 44) proposed for the α -pyrone moiety and analogues

Topology	Atom types	k_p (mdyn·Å·rad ⁻²)	Θ_{ijk} (°)
O-C-O	7-44-41	0.80	118.0
C-O-Lp	44-41-20	0.35	122.2
C-O-C	44-41-2	0.87	118.0
C-C-O	2-44-41	0.70	115.0
O-C-C	7-44-2	0.46	128.0
C-C-C	44-2-2	0.60	121.0
C-C-H	44-2-5	0.24	120.0
C-O-C	1-41-44	0.60	109.9
Lp-O-C	20-41-2	(MM2(91))	
O-C-C	41-2-2	(MM2(91))	
O-C-C	41-2-1	(MM2(91))	
P-C-C	0-2-44	0.2	
P-O-C	0-41-44	0.2	
P-C-C	0-44-1	0.8	out of plane
P-C-C	0-44-2	0.8	plane
P-C-O	0-44-41	0.8	
P-C-O	0-44-7	0.8	

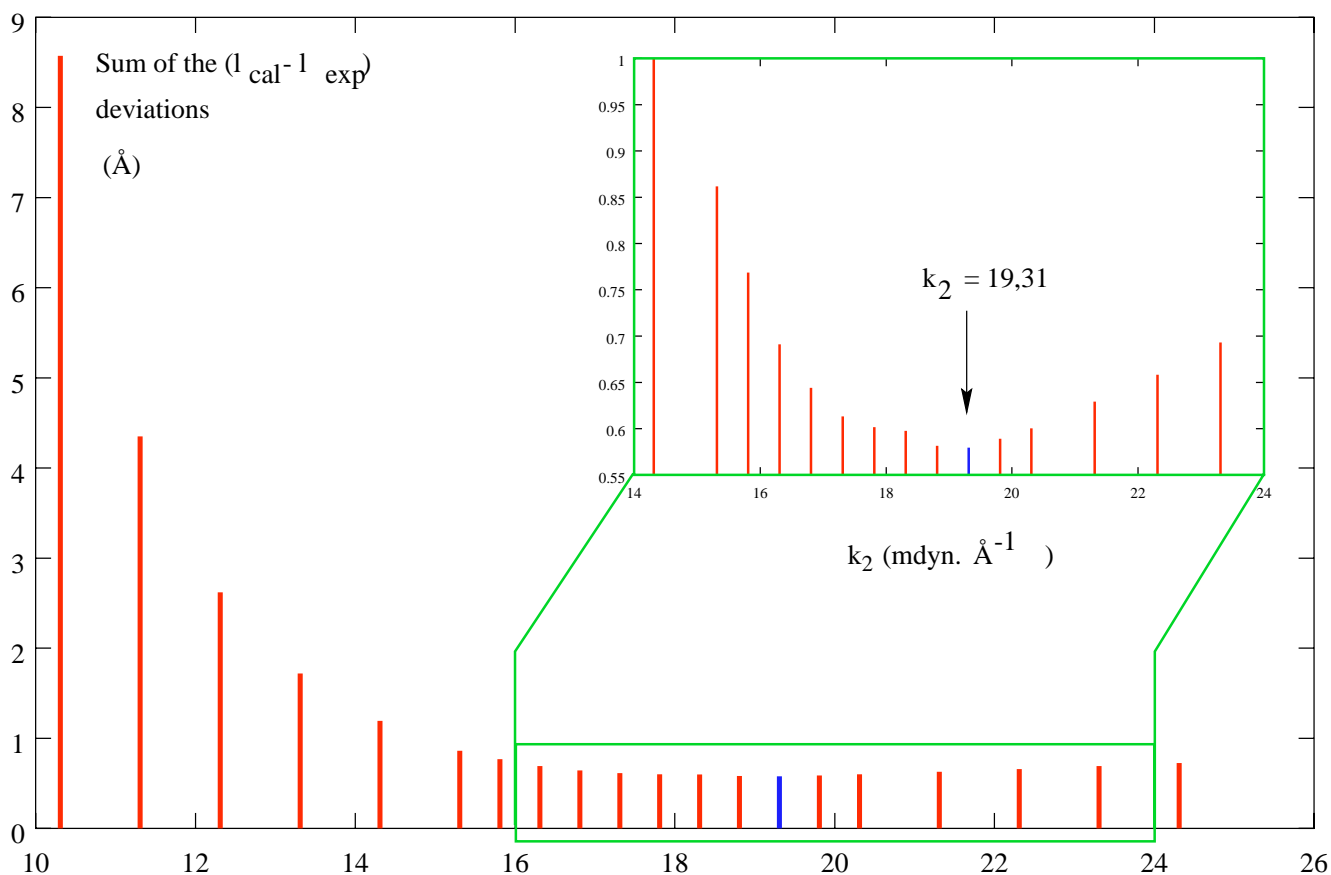


Figure 5 Plot of the sum, for the whole set of reference molecules, of $(l_{cal} - l_{exp})$ deviations for the C(44)-O(41) bond, versus the extrapolated value (for $P = 1$) of the force constant k_2 with $l_2 = 0.708\text{Å}$ and $TSLOPE = 0.977\text{Å}$

Table 6 Stretching parameters proposed for the C(44)-O(41) bond

Atom types	k_2 (mdyn·Å ⁻¹)	l_2 (Å)	σ bond dipole moment (D)	SSLOPE (mdyn·Å ⁻¹)	TSLOPE (Å)
44 41	19.81	0.362	1.79	17.00	1.474

Tables 7 and 8 show the final results obtained on the 20 test molecules (among which 12 were reference molecules and 8 extra molecules) for the part of the molecule we are concerned with (see Fig 8). As can be seen, the results are globally satisfactory. The unsigned mean deviation on the C(44)-C(2) bond length is rather large and possibly shows that the stretching parameters of the C(3)-C(2) bond are not directly transferable to the C(44)-C(2) bond.

Parameterisation of the C(44)-N(40) bond adjacent to a cross-conjugated carbonyl

σ bond dipole moment

The σ bond dipole moment had, here also, to be estimated for two reasons. The only dipole moment known for a C(O)-N bond in the MM2 (91) force field is that for amides in which the separation μ_σ/μ_π is not done (type 9 N atom) and

Table 7a Comparison of the calculated and experimental bond lengths (C44=O7 and C44-O41) for 20 test molecules (a-pyrones and analogues). First 12 molecules were also used as references. Last 8 molecules are extra molecules

No.	C44=O7			C44-O41		
	l_{exp} (Å)	l_{cal} (Å)	$l_{\text{cal}}-l_{\text{exp}}$ (Å)	l_{exp} (Å)	l_{cal} (Å)	$l_{\text{cal}}-l_{\text{exp}}$ (Å)
6	1.2117	1.1987	-0.0130	1.4048	1.4171	0.0123
	1.2050	1.1908	-0.0142	1.3466	1.3943	0.0477
1	1.2043	1.2088	0.0045	1.3680	1.3740	0.0060
17	1.2031	1.2149	0.0118	1.4057	1.4044	-0.0013
19	1.1987	1.1976	-0.0011	1.4480	1.4750	0.0270
26	1.1966	1.2029	0.0063	1.4232	1.4194	-0.0038
27	1.1962	1.1918	-0.0044	1.4019	1.4160	0.0141
42	1.2054	1.1874	-0.0180	1.3919	1.4217	0.0298
	1.2054	1.1874	-0.0180	1.3919	1.4217	0.0298
49	1.1856	1.2161	0.0305	1.3788	1.3874	0.0086
45	1.2046	1.2018	-0.0028	1.4119	1.4157	0.0038
43	1.2181	1.2124	-0.0057	1.4097	1.3759	-0.0338
44	1.2123	1.2122	-0.0001	1.4070	1.3748	-0.0322
51	1.2067	1.2107	0.0040	1.3837	1.3644	-0.0193
56	1.2146	1.2222	0.0076	1.3945	1.4283	0.0338
	1.2155	1.1917	-0.0238	1.3870	1.4589	0.0719
57	1.2053	1.1994	-0.0059	1.4168	1.4603	0.0435
	1.2053	1.2012	-0.0041	1.4168	1.4580	0.0412
58	1.2023	1.2065	0.0042	1.3804	1.3853	0.0049
59	1.1944	1.2082	0.0138	1.3690	1.3358	-0.0332
	1.1944	1.2082	0.0138	1.3690	1.3358	-0.0332
60	1.1887	1.1934	0.0047	1.4020	1.4307	0.0287
61	1.2069	1.2078	0.0009	1.3923	1.3909	-0.0014
21	1.1861	1.1942	0.0081	1.3870	1.4053	0.0183
62	1.2067	1.1965	-0.0102	1.3836	1.4154	0.0318
	1.2043	1.1951	-0.0092	1.3943	1.4230	0.0287
Mean(a)			0.0093			0.0246

(a) Mean of unsigned deviations

Table 7b Comparison of the calculated and experimental bond lengths (O41=C2 and C44-C2-) for 20 test molecules (a-pyrones and analogues). First 12 molecules were also used as references. Last 8 molecules are extra molecules

No.	O41-C2			C44-C2		
	$l_{\text{exp}}(\text{\AA})$	$l_{\text{cal}}(\text{\AA})$	$l_{\text{cal}}-l_{\text{exp}}(\text{\AA})$	$l_{\text{exp}}(\text{\AA})$	$l_{\text{cal}}(\text{\AA})$	$l_{\text{cal}}-l_{\text{exp}}(\text{\AA})$
6	1.3556	1.3750	0.0194	1.4122	1.4713	0.0591
1	1.3739	1.3831	0.0092	1.4755	1.4953	0.0198
17	1.3493	1.3738	0.0245	1.4507	1.4768	0.0261
19	1.3618	1.3729	0.0111	1.4333	1.4674	0.0341
26	1.3581	1.3850	0.0269	1.4433	1.4790	0.0357
27	1.3581	1.3850	0.0269	1.4262	1.4659	0.0397
27	1.3820	1.3731	-0.0089	1.4856	1.4954	0.0098
42	1.3977	1.3835	-0.0142	1.4646	1.4777	0.0131
	1.3977	1.3835	-0.0142	1.4646	1.4777	0.0131
49	1.3528	1.3785	0.0257	1.4517	1.4794	0.0277
45	1.3821	1.3796	-0.0025	1.4588	1.4806	0.0218
43	1.3554	1.3708	0.0154	1.4383	1.4848	0.0465
44	1.3494	1.3718	0.0224	1.4422	1.4831	0.0409
51	1.3583	1.3720	0.0137	1.4386	1.4740	0.0354
56				1.4320	1.4717	0.0397
				1.4280	1.4741	0.0461
57	1.3858	1.3944	0.0086	1.4441	1.4669	0.0228
	1.3858	1.3950	0.0092	1.4441	1.4661	0.0220
58	1.3774	1.3831	0.0057	1.4334	1.4766	0.0432
59	1.4145	1.3754	-0.0391	1.4880	1.4929	0.0049
	1.4145	1.3754	-0.0391	1.4880	1.4929	0.0049
60	1.3883	1.3839	-0.0044	1.4589	1.4693	0.0104
61	1.3802	1.3820	0.0018	1.4551	1.4758	0.0207
21	1.3750	1.3930	0.0180	1.4470	1.4756	0.0286
62	1.3672	1.3783	0.0111	1.4519	1.4740	0.0221
	1.3665	1.3781	0.0116	1.4435	1.4743	0.0308
Mean(a)			0.0155			0.0276

(a) Mean of unsigned deviations

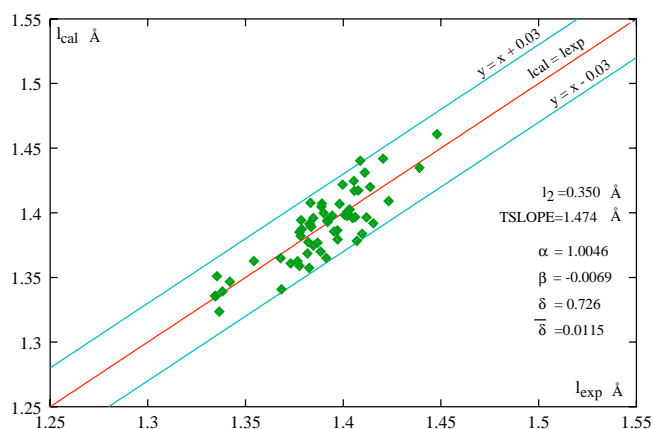
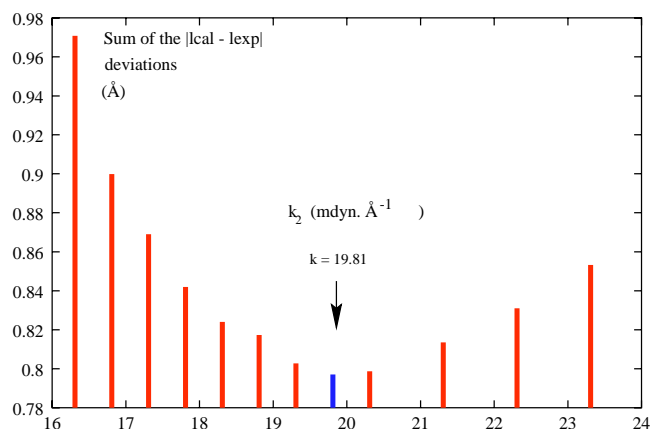
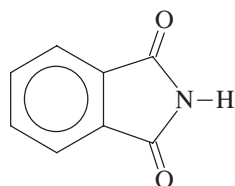
**Figure 6** Comparison between calculated and experimental bond lengths for the C(44)-O(41) bond, with the proposed parameters**Figure 7** Plot of the sum, for the whole set of reference molecules, of $(l_{\text{cal}} - l_{\text{exp}})$ unsigned deviations for the C(44)-O(41) bond, versus the extrapolated value (for $P = 1$) of the force constant k_2 with $l_2 = 0.350$ and $\text{TSLOPE} = 1.474$

Table 8a Comparison of the calculated and experimental bond angles (α -pyrones and analogues). For definition see Fig. 8. First 12 molecules were also used as references. Last 8 molecules are extra molecules

No.	α		β		γ	
	$\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$
6	117.41	-1.93	123.75	1.84	118.76	-0.41
	114.53	3.32	129.02	-2.91	116.45	-0.42
1	117.12	0.37	125.47	-0.48	117.41	0.10
17	130.33	-1.82	115.91	0.86	113.75	0.96
26	119.18	2.03	134.20	-0.53	106.61	-1.54
19	118.07	3.22	132.08	0.20	109.83	-3.41
27	119.86	0.27	130.65	1.02	109.49	-2.17
42	119.57	2.14	135.19	-2.20	105.25	0.06
	119.57	2.13	135.19	-2.20	105.25	0.07
49	116.45	-0.18	127.61	-1.76	115.92	1.96
45	118.36	2.15	132.98	-0.47	108.66	-2.51
43	115.21	1.70	126.47	-1.67	118.31	-0.02
44	115.46	1.83	128.24	-3.40	116.27	1.60
51	116.33	0.37	127.75	-1.52	115.92	1.15
56	115.50	1.47	128.11	-0.71	116.39	-0.75
	114.82	3.46	127.76	-1.30	117.42	-2.16
57	118.99	2.22	135.88	-0.90	105.13	-3.72
	118.99	2.26	135.88	-0.61	105.13	-3.65
58	115.84	1.66	126.97	-1.87	117.18	0.21
59	116.18	-1.95	127.52	-0.26	116.28	2.22
	116.18	-1.94	127.52	-0.27	116.28	2.23
60	120.87	1.03	132.14	1.10	106.97	-2.11
61	116.00	1.43	126.83	-1.70	117.16	0.27
21	120.99	0.92	131.48	1.58	107.53	-2.50
62	116.63	1.40	127.25	-1.94	116.11	0.53
	116.60	1.42	126.42	-1.18	116.97	-0.24
Mean (a)		1.72		1.33		1.42

(a) Mean of unsigned deviations

so the N atom is not included in the π calculation. The second reason is that we have suggested a correction of the π bond dipole moment which has consequential effects on the σ bond dipole moment. Phthalimide (**63**) was chosen as model molecule,



for its symmetry and the availability of its experimental molecular dipole moment. Four values were found in the literature: 2.12D [5], 2.14D [6], 2.91D [7] and 2.17D [8]. The 2.91 value was rejected because the determination was suspected of having been performed on an impure compound

[8] and thus the mean value (2.14 D) was adopted. A calculation by MM2, based on the crystalline geometry, gave the π atomic charges and permitted the calculation of the π bond dipole moments and, from the geometry, a vectorial combination led to the molecular π dipole moment:

$$\mu_{\pi}^{\text{total}} = 3.17\text{D} \quad (5)$$

which is known to be overestimated and must be corrected by a factor which we have suggested to be 0.46 [3]:

$$\mu_{\pi.cor}^{\text{total}} = 0.46 \times 3.17 = 1.46\text{D} \quad (6)$$

It follows that:

$$\mu_{\sigma.cor}^{\text{total}} = \mu_{\text{exp}} - \mu_{\pi.cor}^{\text{total}} = 2.14 - 1.46 = 0.68\text{D} \quad (7)$$

In accordance with the MM2 philosophy, the C(2)-C(2) and C(2)-H(5) bonds were attributed a nul bond dipole moment. It thus results that the $\mu_{\sigma.cor}^{\text{total}}$ is the vectorial sum of the C=O, N-C and N-H σ dipole moments. If we keep Allinger's

Table 8b Comparison of the calculated and experimental bond angles (α -pyrones and analogues). For definition see Fig. 8. First 12 molecules were also used as references. Last 8 molecules are extra molecules

No.	δ		ϵ	
	$\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$
6	121.83	-3.98	117.30	2.25
	121.14	-0.17	122.93	-0.83
1	121.85	-0.29	120.98	0.74
17	122.68	-0.88	123.53	-1.33
26	108.65	0.58	108.62	1.79
19	104.89	1.47	105.52	2.62
27	105.25	1.67	106.05	1.28
42	108.21	0.64	109.97	-0.04
	108.21	0.64	109.97	-0.05
49	123.99	-2.11	119.17	1.00
45	106.44	2.11	106.65	1.95
43	118.67	0.49	120.59	1.15
44	118.82	0.22	124.96	-2.02
51	121.96	-0.53	120.96	0.14
56	124.81	0.31	118.93	1.10
	124.71	0.31	119.73	2.33
57	110.35	2.47	106.88	2.18
	110.35	2.36	106.88	2.05
58	121.31	0.14	121.28	0.42
59	125.50	-2.96	118.69	1.89
	125.50	-2.96	118.69	1.87
60	108.39	0.91	108.07	2.35
61	121.84	-0.32	122.25	-0.64
21	108.97	1.72	107.58	2.21
62	122.05	0.13	122.00	-0.75
	122.13	0.13	120.88	0.36
Mean (a)		1.17		1.36

[a]Mean of unsigned deviations

value for the N-H bond moment and assume that the H atom is correctly located in the X-ray structure, from the value of the C(44)=O(7) σ bond moment already reported (2.10D [1]) and by simple geometrical considerations we find that:

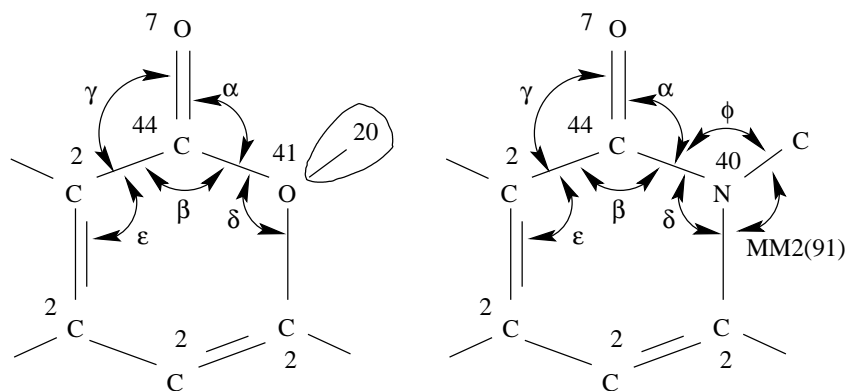
$$\mu_{\sigma}^{44-40} = -0.282D \quad (8)$$

The experimental molecular dipole moments as well as the X-ray structures are also known for three more symmetrical

imides: N-Phenyl-phthalimide (**64**), (2,4,6-trimethylphenyl)-phthalimide (**65**) and Naphtaloimide (**66**). They were thus used to test the value of this σ bond moment as well as other values close to it. (see Table 9).

In the Phthalimide (**63**) and Naphthaloimide (**66**) X-ray structures, the H atom is poorly located which can somewhat perturb the N atom location. So we assumed that the value of -0.31, for which the deviations are lower for the two first molecules, was a better estimation.

Figure 8 Definitions of the angles and bond lengths reported in tables 6, 7, 11 and 12



First estimation of l_2 , k_2 , TSLOPE and SSLOPE stretching parameters

In a first step, we selected in the C.S.D.S., five or six-membered rings for which the exo-bonds on the nitrogen atom were either N-H, N-C, N-N or N-OH. Examination, for 73 values, of the correlation led to:

$$l_{exp} = 1.61 - 0.525 \times P_{exp} \quad (9)$$

with a poor correlation factor: $r = -0.7$.

A closer look to the dispersion of the dots led to the rejection of all but one (72) of the N-H compounds. The main reason being the disturbance of the geometries by intermolecular H-bonding in the crystals. We also rejected the N-N and N-OH derivatives. After rejection, for 28 C(44)-N(40) bonds (25 molecules) the correlation function was:

$$l_{exp} = 1.608 - 0.487 \times P_{exp} \quad (10)$$

with $r = 0.83$ (see Fig 9).

For a first estimation of the variation of the force constant with the π bond order, here also, Badger's rule was used together with Allinger's parameters (see eq(2)). Figure 10 presents the graph of the function obtained by the combination of eq 2 and 10 as well as the dots directly issued from eq 2. The best fit straight line which results is:

$$k_2 = -0.28 + 15.2 \times P_{exp} \quad (11)$$

with $k_1 = -0.28$ and $SSLOPE = 15.2 \text{ md.}\text{\AA}^{-1}$

These first estimations are consistent with the values given by Allinger for the C(3)-N(9) bond in amides. For the l_0 value (MM2(91): 1.385\AA), eq(10) gives an estimation of $\langle P_{exp} \rangle$ (0.45) which, through eq(11), leads to $k_2 = 6.69 \text{ md.}\text{\AA}^{-1}$ (MM2(91) value: 6.40).

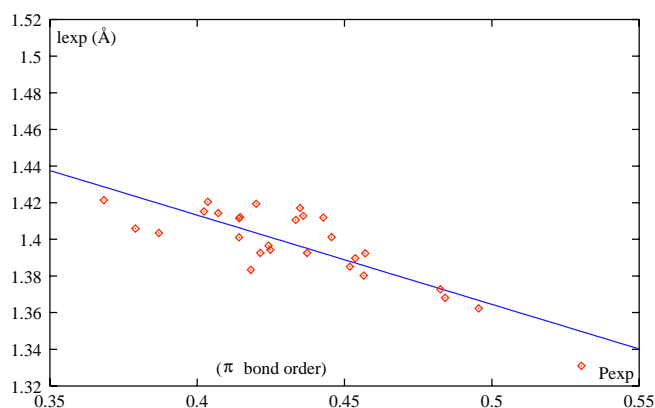


Figure 9 Plot of l_{exp} versus P_{exp} for the adjacent C(44)-N(40) bond in conjugated lactams

Table 9 Calculated molecular dipole moments for some reference molecules for three values of $\mu_{\sigma,corr}^{44-40}$ (see text)

No.	$\mu_{\sigma,corr}^{44-40}$ (D)			μ_{exp} (D)
	-0.25	-0.28	-0.31	
64	2.54	2.51	2.48	2.34
65	2.53	2.50	2.46	2.36
66	4.36	4.33	4.30	4.73
67	2.15	2.14	2.07	2.14

Refinement of the stretching parameters for the C(44)-N(40) bond

Determination of l_2 , TSLOPE and k_2 , SSLOPE from the first "statistical estimation" was performed in the same way as for the adjacent C(44)-O(41) bond (see above) using the programs previously constructed [1].

Simulations were run while fixing the positions of all the heavy atoms (but the N atom) as well as the O(7)=C(44)-N(40)-C(2) dihedral angle. First, for the above values of k_2 and SSLOPE, successive grid searches led to:

$$l_2 = l_1 - TSLOPE = 0.980 \text{ \AA} \quad (12)$$

with TSLOPE = 0.718 \AA and satisfy the criteria:

$$l_{cal} = \alpha \times l_{exp} + \beta \quad (13)$$

with $\alpha = 1.00222$ $r = 0.78$

$\beta = 0.00242$ $\delta = 0.368$ (for 28 bonds)

Then, with these values and considering a SSLOPE value of 15.2 , k_2 was optimised by trial and error to lower δ . In this way a better estimation of k_2 (16.9) was reached. Critical examination of the results nevertheless showed that a rather large dispersion mainly resulted from the fact that, in numer-

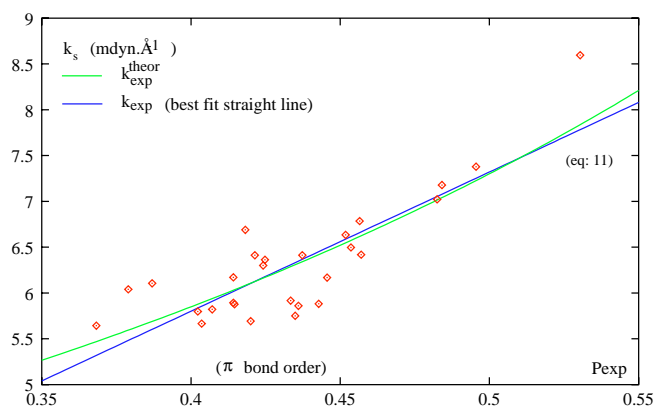


Figure 10 Plot of k_{exp} versus P_{exp} for the adjacent C(44)-N(40) bond in conjugated lactams

Table 10 Bending parameters involving the nitrogen atom (type 40) in conjugated «lactams». Parameters involving the cross-conjugated C atom (type 44) are revised parameters

Topology	Atom type	k_2 (mdyn·Å·rad ⁻²)	Θ_{ijk} (°)
O-C-N	7-44-40	0.67	120.0
C-O-C	44-40-2	0.60	126.0
C-C-N	2-44-40	0.45	115.0
C-N-C	44-40-1	0.76	117.0
N-C-C	40-2-2	(MM2(91))	
	40-2-1	(MM2(91))	
C-N-H	44-40-23	0.42	119.0
		values of (MM2(91)) for C(3)-N(9)-H(28)	
P-N-C	0-40-44	0.2	out of plane
P-C-N	0-44-40	0.8	

ous molecules, the N atom was at the hinge of fused rings, thus being itself cross-conjugated. So, in accordance with our philosophy, it deserves a special type number. After rejecting molecules of that type, the remaining eleven led to $k_2 = 16.3 \text{ md}\cdot\text{Å}^{-1}$. With this value, a better correlation was obtained with:

$$l_2 = 1.002 \text{ Å} \quad \text{TSLOPE} = 0.688 \text{ Å}$$

$$\alpha = 1.00407 \quad r = 0.953$$

$$\beta = 0.00252 \quad \delta = 0.1143$$

Finally, alternating refinements of (l_2 , TSLOPE) and (k_2 , SSLOPE) led to:

$$l_2 = 1.002 \text{ Å} \quad \text{TSLOPE} = 0.685 \text{ Å}$$

$$k_2 = 20.5 \text{ md}\cdot\text{Å}^{-1} \quad \text{SSLOPE} = 15.2 \text{ md}\cdot\text{Å}^{-1}$$

As for the parameterisation of the C(44)-O(41) bond, it was then necessary to improve the bending parameters for the angles containing both the C(44) and N(40) atoms. That is to say: O(7)-C(44)-N(40) called α , C(2)-C(44)-N(40) (β), C(2)-N(40)-C(44) (δ) and C(1)-N(40)-C(44) (ϕ) angles. The C(2)-C(44)-O(7) (γ) and C(2)-C(2)-C(44) (ϵ) angles were examined previously (see above).

Because the adjustment of these angles was not severe, the bending force constants were assumed to be identical to those found in MM2(91) replacing C(44) by C(3). Only the "natural" angles were slightly modified to minimise the sum of the unsigned deviations. The Θ_{ijk}° angles found (giving a mean of unsigned deviations of $0^\circ 73$) are reported in Table 10. The finally proposed stretching parameters are given in Table 11. As it can be seen, the agreement of l_{cal} with l_{exp} is satisfactory.

Tables 12 and 13 show the final results obtained after complete optimisation of 28 test-molecules. The first 10 were already used as reference molecules, i.e. to set up the param-

eters. Among them **72** is an exception for it contains an N-H bond (see above).

The following 11 are extra molecules containing either a nitrogen atom at the hinge of fused rings (one of which can be unconjugated) or an N-Ph exo-bond (**81**). For these molecules there is a possibility of cross-conjugation of the N atom itself, in which case it should be attributed a special atom type and special parameters. Compound **86** is mentioned here because it is also an exception in that it contains several C atoms which could be cross-conjugated. The last 7 are molecules containing an exo N-H (40-23) bond which give rise to cyclic dimers by hydrogen bonding. The last two categories were excluded from the determination of the parameters but it was interesting to see to what extent they could be suitable in these special cases.

The global mean of unsigned deviations for the C(44)-N(40) bond length (0.0222 Å) is comparable to the global mean for the N(40)-C(2) bond length (0.0227 Å) for which we used the MM2(91) resident parameters and compares favourably with that obtained for the similarly adjacent C(44)-O(41) bond (0.0246 Å).

The results concerning fused ring moieties are not as good. When both rings are conjugated, the poor results were expected for the reasons already presented, but when only one ring is conjugated the reasons for the discrepancy are unclear.

Results for the N-H compounds, on the other hand, are very good although they were not included in the statistical study (**72** is the sole exception). The discrepancies on the C(44)-C(2) adjacent bond confirm – as was suspected – that the C(3)-C(2) parameters are not transferable when the C atom is cross-conjugated. The means of unsigned deviations

Table 11 Stretching parameters proposed for the C(44)-N(40) bond

Atom types	k_2 (mdyn·Å ⁻¹)	l_2 (Å)	σ bond dipole moment (D)	SSLOPE (mdyn·Å ⁻¹)	TSLOPE (Å)
44 40	20.60	0.950	-0.31	15.2	0.790

Table 12a Comparison of the calculated and experimental bond lengths for 28 molecules (conjugated "lactams" and analogues)

No. [a]	N40-C2 or N40-C1[b]			C44-C2		
	$l_{\text{exp}}(\text{\AA})$	$l_{\text{cal}}(\text{\AA})$	$l_{\text{cal}}-l_{\text{exp}}(\text{\AA})$	$l_{\text{exp}}(\text{\AA})$	$l_{\text{cal}}(\text{\AA})$	$l_{\text{cal}}-l_{\text{exp}}(\text{\AA})$
67	1.4697*	1.4636	-0.0061	1.4799	1.4935	0.0136
68	1.3557	1.3985	0.0428	1.4463	1.4748	0.0285
69	1.5163*	1.4701	-0.0462	1.5515	1.4869	-0.0646
70	1.3676	1.3915	0.0239	1.4330	1.4721	0.0391
71	1.3502	1.4046	0.0544	1.4529[c]	1.4692	0.0433
				1.4549[d]	1.4752	0.0203
72	1.4043	1.4009	-0.0034	1.4429	1.4740	0.0311
73	1.3551	1.3911	0.0360	1.4412	1.4743	0.0331
74	1.3442	1.3905	0.0463	1.4478	1.4740	0.0262
75	1.3829	1.4103	0.0274	1.4319	1.4721	0.0402
76	1.3967	1.4287	0.0320	1.4378	1.4705	0.0327
Mean [g]			0.0319			0.0339
77	1.3820[e]	1.3946	0.0126	1.4526	1.4841	0.0315
	1.4000[f]	1.4248	0.0248			
78	1.3783[e]	1.3913	0.0130	1.4685	1.4859	0.0174
	1.4186[f]	1.4227	0.0041			
79	1.3805[e]	1.3942	0.0137	1.4731	1.4848	0.0117
	1.4270[f]	1.4237	-0.0033			
80	1.3821[e]	1.4123	0.0302	1.4246	1.4684	0.0438
81	1.4017[e]	1.4202	0.0185	1.4519	1.4705	0.0186
82	1.3916[e]	1.3888	-0.0028	1.4335	1.4793	0.0458
83	1.3723[e]	1.3936	0.0213	1.4067	1.4628	0.0561
	1.3864[f]	1.4048	0.0184			
84	1.3678[e]	1.3719	0.0041	1.5046	1.4846	-0.0200
	1.4137[f]	1.4097	-0.0040			
85	1.3732[e]	1.4105	0.0373	1.4261	1.4684	0.0423
86	1.4115[e]	1.4307	0.0192	1.4539	1.4825	0.0286
87	1.3724[e]	1.3923	0.0199	1.4662	1.4841	0.0179
	1.4217[f]	1.4237	0.0020			
Mean [g]			0.0147			0.0303
88	1.3940	1.4058	0.0118	1.4468	1.4728	0.0260
89	1.3794	1.4041	0.0247	1.4375	1.4736	0.0361
90	1.3588	1.3854	0.0266	1.4129	1.4649	0.0520
91	1.3556	1.3899	0.0343	1.4169	1.4680	0.0511
92	1.3961	1.4006	0.0045	1.4483	1.4742	0.0259
93	1.3713	1.3921	0.0208	1.4287	1.4647	0.0360
94	1.3623	1.3895	0.0272	1.4335	1.4680	0.0345
Mean [g]			0.0214			0.0374
Global Mean [h]			0.0227			0.0339

[a] For the definitions of the 3 categories of test molecules please see text

[b] The bond lengths marked with an asterisk are actually N(40)-C(1) bond lengths enclosed in the ring

[c] Bond close to a N atom

[d] Bond close to an O atom

[e] N(40)-C(2) bond which belongs to the «lactam» ring

[f] N(40)-C(2) bond exo to the «lactam» ring

[g] Mean of unsigned deviations

[h] The global mean is the sum of the means for the 3 categories of compounds divided by 3

Table 12b Comparison of the calculated and experimental bond lengths for 28 molecules (conjugated "lactams" and analogues)

No. [a]	C44=O7			C44-N40		
	l_{exp} (Å)	l_{cal} (Å)	$l_{\text{cal}}-l_{\text{exp}}$ (Å)	l_{exp} (Å)	l_{cal} (Å)	$l_{\text{cal}}-l_{\text{exp}}$ (Å)
67	1.2458	1.2536	0.0078	1.3309	1.3161	-0.0148
68	1.2225	1.2643	0.0418	1.4106	1.3685	-0.0421
69	1.2090	1.2539	0.0449	1.3623	1.3270	-0.0353
70	1.2402	1.2603	0.0201	1.3926	1.3885	-0.0041
71	1.2219[c]	1.2227	0.0008	1.4011	1.4220	0.0209
	1.1961[d]	1.1729	-0.0232			
72	1.2465	1.2463	-0.0002	1.3897	1.3673	-0.0224
73	1.2335	1.2225	-0.0110	1.4115	1.4209	0.0094
74	1.2173	1.2207	0.0034	1.4152	1.4259	0.0107
75	1.2423	1.2804	0.0381	1.3728	1.3352	-0.0376
76	1.2319	1.2570	0.0251	1.3851	1.3733	-0.0118
Mean [g]			0.0196			0.0209
77	1.2503	1.2308	-0.0195	1.4194	1.4085	-0.0109
78	1.2244	1.2203	-0.0041	1.3943	1.4230	0.0287
79	1.2097	1.2277	0.0180	1.3965	1.4114	0.0149
80	1.2405	1.2605	0.0200	1.4012	1.3746	-0.0266
81	1.2325	1.2661	0.0336	1.4119	1.3665	-0.0454
82	1.2562	1.2735	0.0173	1.3681	1.3410	-0.0271
83	1.2339	1.2316	-0.0023	1.4214	1.4555	0.0341
84	1.1994	1.2151	0.0157	1.4035	1.4602	0.0567
85	1.2360	1.2596	0.0236	1.4128	1.3764	-0.0364
86	1.2107	1.2554	0.0447	1.4171	1.3674	-0.0497
87	1.2200	1.2331	0.0131	1.3926	1.4210	0.0284
Mean [g]			0.0193			0.0326
88	1.2423	1.2572	0.0149	1.3713	1.3523	-0.0190
89	1.2456	1.2562	0.0106	1.3723	1.3565	-0.0158
90	1.2614	1.2659	0.0045	1.3607	1.3668	0.0061
91	1.2506	1.2646	0.0140	1.3639	1.3582	-0.0057
92	1.2415	1.2570	0.0155	1.3661	1.3529	-0.0132
93	1.2449	1.2524	0.0075	1.3676	1.3824	0.0148
94	1.2512	1.2634	0.0122	1.3772	1.3601	-0.0171
Mean [g]			0.0113			0.0131
Mean [h]			0.0167			0.0222

[a] For the definitions of the 3 categories of test molecules please see text

[b] The bond lengths marked with an asterisk are actually N(40)-C(1) bond lengths enclosed in the ring

[c] Bond close to a N atom

[d] Bond close to an O atom

[e] N(40)-C(2) bond which belongs to the «lactam» ring

[f] N(40)-C(2) bond exo to the «lactam» ring

[g] Mean of unsigned deviations

[h] The global mean is the sum of the means for the 3 categories of compounds divided by 3

Table 13a Comparison of the calculated and experimental bond angles for 28 molecules (conjugated "lactams" and analogues)

No. [a]	O(7)=C(44)-N(40)		C(2)-C(44)-N(40)		O(7)=C(44)-C(2)	
	$\Theta_{\text{exp}}(^{\circ})$	α [b] $\Theta_{\text{cal}}-\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	β [b] $\Theta_{\text{cal}}-\Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	γ [b] $\Theta_{\text{cal}}-\Theta_{\text{exp}}(^{\circ})$
67	121.15	-0.79	117.54	0.83	121.25	0.02
68	119.54	-0.11	114.99	1.38	125.45	-1.25
69	122.11	-2.47	117.04	2.88	120.78	-0.35
70	117.99	1.07	116.97	-0.56	125.05	-0.53
71	119.92	1.84	112.61	0.69	127.47[d]	-2.53
					131.52[e]	1.07
72	119.67	-1.91	116.47	-1.40	123.85	3.32
73	119.39	0.73	115.26	-0.30	125.35	-0.43
74	119.71	0.45	113.86	0.96	126.43	-1.41
75	120.85	0.66	115.68	0.68	123.47	-1.34
76	121.26	-0.08	115.93	0.26	122.81	-0.18
Mean [g]		1.01		0.99		1.15
77	119.06	1.11	115.72	-1.93	125.22	0.82
78	120.84	-0.72	114.00	-0.41	125.16	1.14
79	121.77	-1.58	112.85	0.94	125.38	0.64
80	118.95	1.45	115.76	0.37	125.29	-1.82
81	119.40	-0.89	113.74	4.03	126.86	-3.14
82	119.89	-0.70	115.23	-0.87	124.87	1.58
83	118.11	1.73	112.63	0.81	129.26	-2.53
84	120.84	-1.71	114.41	-0.04	124.69	1.81
85	118.81	1.68	115.01	1.05	126.16	-2.73
86	119.66	-0.02	116.69	0.65	123.63	-0.63
87	121.26	-1.54	113.84	0.26	124.90	1.28
Mean [g]		1.19		1.03		1.65
88	120.24	-2.65	116.40	-1.01	123.36	3.66
89	120.36	-2.52	115.55	-0.34	124.06	2.89
90	118.44	-0.57	117.23	-2.45	124.32	3.03
91	120.15	-2.25	114.60	0.25	125.25	2.00
92	121.07	-3.36	115.75	-0.46	123.17	3.83
93	120.45	-2.41	114.84	-0.41	124.67	2.86
94	120.35	-2.45	114.97	-0.11	124.68	2.56
Mean [g]		2.32		0.72		2.98
Global mean [h]		1.51		0.91		1.97

[a] For the definitions of the 3 categories of test-molecules, please see text

[b] For the definitions of bond angles, please see Fig 8

[c] The angles marked with an asterisk correspond to the definition of Fig 8, but the C atom is type 1 not type 2

[d] γ angle opposite to the N atom. ϵ angle in the "lactam" ring

[e] γ angle opposite to the O atom. ϵ angle in the "lactone" ring

[f] In this compound the exo N-C bond is replaced by an N-H bond

[g] Mean of unsigned deviations

[h] The global mean is the sum of the means for the 3 categories of compounds divided by 3.

Table 13b Comparison of the calculated and experimental bond angles for 28 molecules (conjugated "lactams" and analogues)

No. [a]	C(44)-N(40)-C(2) or C(44)-N(40)-C(1) [c]		C(44)-C(2)-C(2)		C(44)-N(40)-C(2) or C(44)-N(40)-C(1) [c]	
	$\Theta_{\text{exp}}(^{\circ})$	δ [b] $\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	ϵ [b] $\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$	$\Theta_{\text{exp}}(^{\circ})$	ϕ [b] $\Theta_{\text{cal}} - \Theta_{\text{exp}}(^{\circ})$
67	120.15*	-1.93	122.04	-0.03	121.34*	-2.02
68	123.18	-0.26	120.32	0.47	116.41*	0.86
69	122.91*	-2.29	118.56	2.84	116.41*	0.26
70	121.26	1.37	120.96	0.14	118.52*	-1.21
71	123.34	-0.22	123.33[d]	-0.45	117.06*	1.62
			108.87[e]	-0.69		
72	123.91	1.85	120.27	1.35	[f]	
73	122.78	-0.03	121.48	0.53	117.11*	-0.15
74	123.12	-0.39	122.31	-0.35	115.44*	1.48
75	122.17	0.82	121.71	-0.03	118.29*	-0.01
76	123.30	-0.30	122.39	1.24	116.40*	1.01
Mean [g]		0.95		0.74		0.96
77	119.00	2.44	123.33	0.61	132.79	0.05
78	121.43	-0.18	124.28	-0.26	130.98	2.07
79	121.96	-0.47	125.45	-1.54	130.80	2.04
80	122.41	0.78	121.19	0.31	114.59*	1.79
81	123.90	-1.79	122.27	-1.47	115.98	2.84
82	125.16	0.73	119.99	0.76	122.77*	-0.19
83	125.10	-1.73	122.89	0.48	125.53	2.53
84	121.69	-0.92	122.50	0.92	130.58	1.68
85	122.23	0.98	122.49	-0.98	113.89*	2.80
86	122.90	0.67	118.73	1.37	116.69*	1.14
87	121.60	-0.26	124.37	-1.15	130.77	2.17
Mean [g]		1.00		0.90	(44-40-1)	1.48
					(44-40-2)	1.91
88	124.16	2.11	121.06	0.38	.	
89	124.05	1.75	121.60	0.13	.	
90	122.64	2.04	123.43	-1.86	.	
91	124.75	0.47	121.39	0.03	[f]	
92	125.67	-0.05	120.02	1.77	.	
93	125.35	1.13	121.05	-0.07	.	
94	124.39	0.72	121.16	0.17	.	
Mean [g]		1.18		0.63		
Global mean [h]		1.13		0.76	(44-40-1)	1.22
					(44-40-2)	1.91

[a] For the definitions of the 3 categories of test-molecules, please see text

[b] For the definitions of bond angles, please see Fig 8

[c] The angles marked with an asterisk correspond to the definition of Fig 8, but the C atom is type 1 not type 2

[d] γ angle opposite to the N atom. ϵ angle in the "lactam" ring

[e] γ angle opposite to the O atom. ϵ angle in the "lactone" ring

[f] In this compound the exo N-C bond is replaced by an N-H bond

[g] Mean of unsigned deviations

[h] The global mean is the sum of the means for the 3 categories of compounds divided by 3. (ϕ is an exception)

on the angles of interest are globally satisfying. They are only especially large for the α and γ angles of the N-H compounds. Here, the deviations are correlated (same order of magnitude but opposite signs) and concern the orientation of the C(44)=O(7) bond with regards to the ring. One could suspect the formation of cyclic dimers in the crystals to alter these angles but the similar behaviour of **73** suggests that this could be the consequence of an inappropriate transfer of the bending parameters of the C(3)-N(9)-H(28) moiety to the C(44)-N(40)-H(23). The usually poor localisation of the H atoms by X-rays prevented us from trying to improve these parameters.

Conclusion

The definition, in a previous paper, of a new type of carbonyl C atom (type 44) in the MM2 force field, i.e. when it is cross-conjugated has led us, after reparameterisation of the C=O bond itself, to the parameterisation of adjacent heterocycle bonds. By means of a statistical study based on data from the C.S.D.S., we propose here some new stretching parameters and σ dipole moments for the C(44)-O(41) and C(44)-N(40) bonds. These parameters are π -bond-order dependent and are globally satisfactory within limited π bond order ranges: 0.25 to 0.32 for the C-O bond, 0.37 to 0.53 for the C-N bond. They were set up assuming that the other adjacent bond type was 44-2. It was also assumed that the C(3)-C(2) parameters were transferable to it. This has two consequences.

First, the proposed parameters are satisfactory for conjugated «lactones» and «lactams» but would not be suited to, for instance, organic carbonates, ureas, etc.

Second, as the present study has shown large deviations concerning the C(44)-C(2) bond length, an effective parameterisation of that bond has proved to be necessary and is currently being undertaken. This could be responsible for part of the deviations observed on bond lengths (maximum 0.03Å). Another part could be due to, as mentioned earlier, the sensitivity of the length of polar bonds to the variation of the effective dielectric constant D from one crystal to another.

The remark concerning the difference between r_g and r_α made in the previous paper [1] is, of course, still valid. Earlier works published on lactams and lactones presenting some conjugation are listed in the previous paper (ref 15 to 18 of [1]). In the MM2 calculations of conjugated amides Berg and Bladh [9] have a philosophy which differs from ours. The type of the carbonyl C atom remains 3. The N atom however is included in the π calculation (type 9*).

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In the present paper, the section concerning the C(44)-O(41) bond is part of Dr J-Ph Rameau's thesis [10].

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