Acta Crystallographica Section C
Crystal Structure Communications
ISSN 0108-2701

Two derivatives of (*N*-phenylthioureidoalkyl)phosphonates

Lilianna Chęcińska,[a]* Lesław Sieroń,[b] Maria Bukowska-Strzyżewska,[b] Zbigniew H. Kudzin[c] and László Fábián[d]

[a]Department of Crystallography and Crystallochemistry, University of Łódź, Pomorska 149/153, 90-236 Łódź, Poland, [b]Institute of General and Ecological Chemistry, Technical University of Łódź, Żwirki 36, 90-924 Łódź, Poland, [c]Department of Organic Chemistry, University of Łódź, Narutowicza 68, 90-136 Łódź, Poland, and [d]Institute of Chemistry, Chemical Research Centre of the Hungarian Academy of Sciences, PO Box 17, Budapest, H-1525 Hungary
Correspondence e-mail: lilach@krysia.uni.lodz.pl

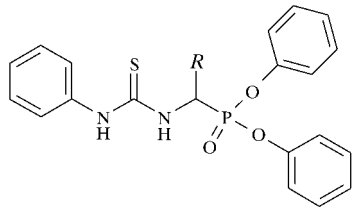
Received 20 September 2002
Accepted 26 November 2002
Online 17 December 2002

The structures of diphenyl [3-methyl-1-(3-phenylthioureido)-butyl]phosphonate and diphenyl [2-methyl-1-(3-phenylthioureido)butyl]phosphonate, both $C_{24}H_{27}N_2O_3PS$, are reported. In both compounds, the thiourea moiety adopts a *syn–syn* conformation (*i.e.* the S—C—N—C torsion angles are synperiplanar), which enables N—H···O hydrogen bonds to be formed between centrosymmetrically related molecules. The geometries around the P atoms can be described as distorted tetrahedral. Some of the functional groups in each structure are disordered. The bulk of the different alkyl substituents between the amide and phosphonate groups influences the molecular conformation and crystal packing. Although the structures of these compounds and two related derivatives appear to be similar, they are not isostructural.

Comment

This paper is part of our systematic investigations of organophosphorus derivatives of thiourea (Chęcińska *et al.*, 2001*a*,*b*). Diphenyl (*N*-phenylthioureidoalkyl)phosphonates have applications in the synthesis of phosphonic analogues of natural amino acids (Kudzin & Stec, 1978). Moreover, this class of phosphonates presents a structural analogy to phenylthiocarbamoylamino acids and is therefore considered to represent compounds with the potential for biological activity. Here, the crystal structures of two compounds in this class, namely diphenyl [3-methyl-1-(3-phenylthioureido)butyl]-phosphonate, (I), and diphenyl [2-methyl-1-(3-phenylthioureido)butyl]phosphonate, (II), are reported.

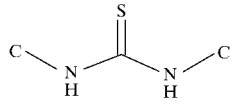
The title compounds (Figs. 1 and 2) differ only in the nature of the substituent attached to methine atom C2, namely an isobutyl butyl group for (I) and a *sec*-butyl group for (II). Both structures exhibit positional disorder (see *Experimental*). In (I), two methyl groups are disordered, with site-occupancy factors of 0.673 (9) and 0.327 (9). In (II), one phenyl ring, C21–C26, of the phosphonate group is positionally disordered over two orientations with equal site occupancies. The dihedral angle between the best planes of the disordered orientations of this phenyl ring is 4.4 (2)°.



(I) $R = (CH_3)_2CHCH_2-$
(II) $R = CH_3CH_2(CH_3)CH-$

As expected, the thioureide groups are planar in both structures. The maximum deviation of atoms H1 and H2 from the mean planes defined by atoms S1, C1, N1 and N2 is 0.03 (2) Å for H1 of (I). The S1═C1 bond lengths in (I) and (II) are slightly shorter than the unweighted mean value of 1.681 Å for thioureas (Allen *et al.*, 1987). Nevertheless, the geometries of the thioureide groups in (I) and (II) are similar; neither the N—Csp^2 (N1—C1 or N2—C1) distances nor the S1—C1—N1 or S1—C1—N2 angles differ significantly.

In both compounds, the two substituents of the thioureide group (the phenyl ring and the butylphosphonate group) adopt a *syn–syn* conformation with respect to the thiourea moiety (see torsion angles in Tables 1 and 3). The *syn–syn* conformation, found here, is rarely observed. A search of the Cambridge Structural Database (Version 5.23, April 2002 release; Allen, 2002) for structures containing the $SC(NHC)_2$ fragment of (I) and (II) (restraints: the S atom is terminal and the N—C bonds are acyclic; see *Scheme* below) revealed 70 fragments (62 refcodes). Among these structures, only 11 examples have the substituents in a *syn–syn* conformation, with the S—C—N—C torsion angles within the range 0±11°. In the other thiourea compounds, the *syn–anti* conformation is preferred.



In both title compounds, the *syn–syn* conformation of the thiourea fragment enables the formation of N—H···O hydrogen bonds between pairs of molecules related by a centre of inversion. As a result, characteristic dimers are formed (Figs. 3 and 4). Combination of the intermolecular N1—H1···O1^{i} and N2—H2···O1^{i} hydrogen bonds [symmetry code: (i) $-x, -y, -z$ for (I); $1-x, 1-y, 1-z$ for (II)] creates a loop pattern, with a binary graph-set descriptor (Bernstein *et al.*, 1995) of $R_2^1(6)$. The hydrogen bonds within this motif have very similar geometries and are almost symmetric.

For the structures of the analogous C2-methyl, (III), and C2-isopropyl, (IV), derivatives of (*N*-phenylthioureidoalkyl)-phosphonates, reported earlier by Chęcińska *et al.* (2001*a*,*b*), an identical hydrogen-bonding pattern was found. Considering the related structures of (I)–(IV) together, it is interesting to compare the distances between the hydrogen-bond

  DOI: 10.1107/S0108270102021820

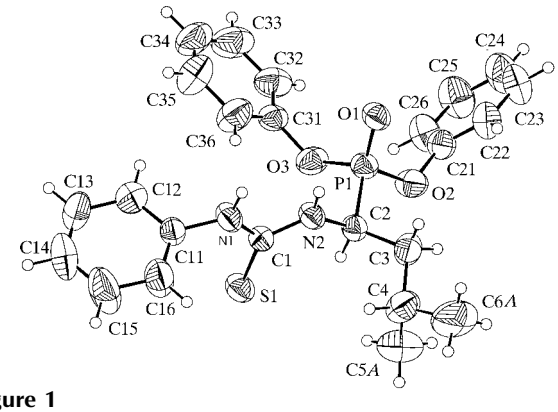


Figure 1
The molecular structure of (I) with the atom-numbering scheme. The minor disorder components (atoms C5*B* and C6*B*) have been omitted for clarity. Displacement ellipsoids are drawn at the 40% probability level and H atoms are shown as small spheres of arbitrary radii.

donors and accceptors. The mean intermolecular N···O distance increases in the order (III) [2.897 (3) Å], (I) [2.916 (3) Å], (II) [2.953 (2) Å] and (IV) [2.954 (3) Å], in accordance with the steric bulk of the substituent attached to methine atom C2. Although the C2 substituent has the same number of atoms in (I) and (II), the mean N···O distances are different. The substitution at atom C3 [in (II) and (IV)] generates distinctly greater steric hindrance between the molecules of the hydrogen-bonded dimer than does subsitution at atom C4 [in (I)].

The coordination of the P atom in each structure is slightly distorted tetrahedral. The deformations of the tetrahedra can be explained by the steric effects of the different substituents and bond types, *viz*. the double P1═O1 and single P1—C2 bonds. The spatial requirements of the different substituents at C2 in the structures of (I)–(IV) also have an influence on the angular deformation of the PO_3C tetrahedra. In (III), (I), (IV) and (II) (with substituents Me, ^{i}Bu, ^{i}Pr and *sec*-Bu, respectively), the C2—P1—O1 angles are 113.74 (12), 115.25 (12), 116.26 (10) and 116.82 (10)°, respectively, while

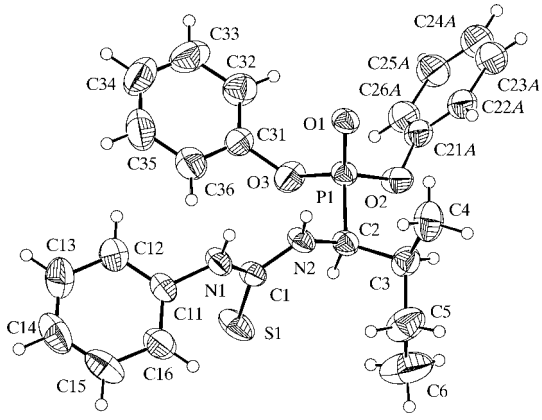


Figure 2
The molecular structure of (II) with the atom-numbering scheme. The second component of the disordered phenyl ring (C21*B*–C26*B*) has been omitted for clarity. Displacement ellipsoids are drawn at the 40% probability level and H atoms are shown as small spheres of arbitrary radii.

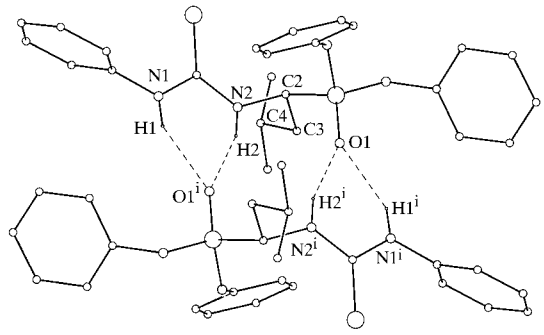


Figure 3
The hydrogen-bonded dimers in (I) [symmetry code: (i) $-x$, $-y$, $-z$]. H atoms bonded to C atoms have been omitted.

the C2—P1—O3 angles are 107.37 (11), 105.40 (11), 105.32 (11) and 104.85 (10)°, respectively. In other words, the size of the C2 substituents and the mode of their embranchment influence both the molecular structure and the relative positions of the molecules in the hydrogen-bonded dimers.

The molecular structures of compounds (I) and (II) are similar to those of (III) and (IV) (Chęcińska *et al.*, 2001*a*,*b*), which suggests that their crystals may be isostructural. The pairs of compounds (I)/(III) and (II)/(IV) crystallize in the same space group [a transformation from space group $P2_1/n$ to $P2_1/c$ is needed for (IV)]. A basic prerequisite of isostructurality is similarity of the unit cells, which can be estimated by means of the Π index $[(a+b+c/a'+b'+c')-1$, where a, b, c, a', b' and c' are the orthogonalized lattice parameters; Fábián & Kálmán, 1999]. For the crystal pairs (I)/(III) and (II)/(IV), the Π values are 0.031 and 0.045, respectively. In the latter case, however, the Π index is misleading, since the differences between the b and c axes compensate each other (Table 5).

Despite some degree of similarity between the unit cells, the structures are not isostructural, which is shown by the low values of the volumetric isostructurality index, I_v [percentage ratio of the overlapping volume of molecules in analysed structures to the average of the corresponding molecular volumes; Fábián & Kálmán, 1999]. This parameter is 19.1% for (I)/(III) and 30% for (II)/(IV); for isostructural pairs, I_v is close to 100%. The structures compared here are not

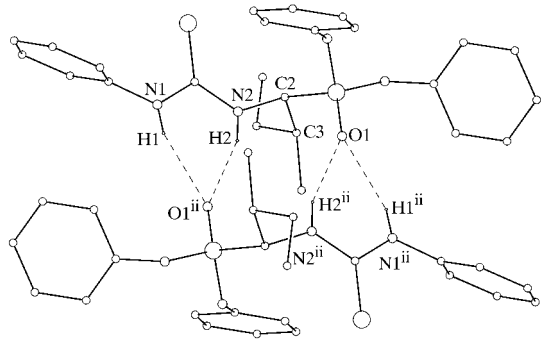


Figure 4
The hydrogen-bonded dimers in (II) [symmetry code: (ii) $1-x$, $1-y$, $1-z$]. H atoms bonded to C atoms have been omitted.

isostructural because of the different arrangements of the molecules in their crystal lattices. This observation prompted further investigation into why these molecules exhibit different packing motifs. In order to answer this question, a detailed analysis of the conformations of the structures presented here was performed.

The isobutyl and methyl derivatives, (I) and (III), have significantly different molecular conformations (Fig. 5). The main difference is that the bulky phenyl groups have different orientations in (I) and (III), and the dihedral angles between the best planes of the corresponding phenyl rings in (I) and (III) differ by 0.2–45.7 (1)°. It is likely that the different steric requirements of the C2 substituents result in different packing arrangements for (I) and (III), which then influences the conformation of the molecules.

In contrast, the conformations of the molecules of (II) and (IV) are similar (Fig. 6). There are no significant differences between the bond lengths and angles of (II) and (IV), and the dihedral angles between the best planes of the phenyl rings differ by not more than 4.2 (1)°. However, despite their conformational similarity, the packing arrangements of the molecules of (II) and (IV) in their crystals differ (Figs. 7 and 8). Nevertheless, both structures comprise similar columns of hydrogen-bonded dimers (see the central columns of molecules in Figs. 7 and 8). The presence of a common pattern that is infinite in one dimension can be termed one-dimensional isostructurality.

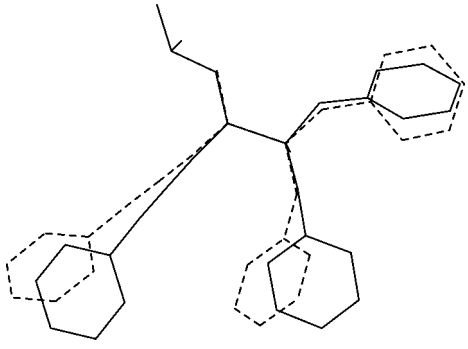


Figure 5
A superposition of the skeletons of (I) (continuous line) and (III) (dashed line), viewed down the S1—C1 bond.

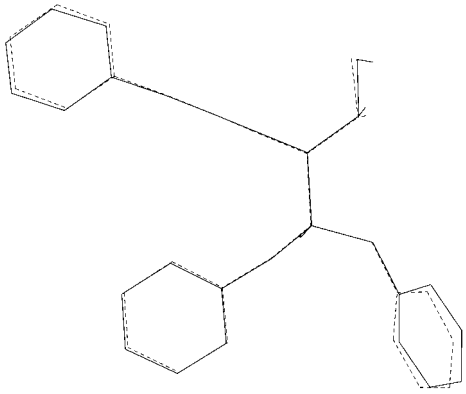


Figure 6
A superposition of the skeletons of (II) (continuous line) and (IV) (dashed line), viewed down the S1—C1 bond.

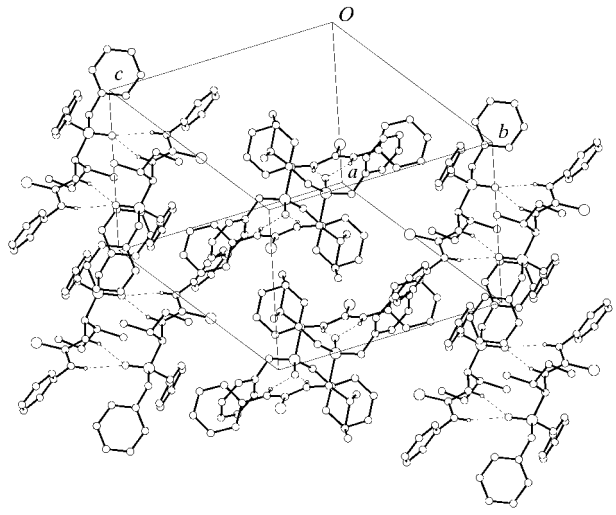


Figure 7
The crystal packing of (II).

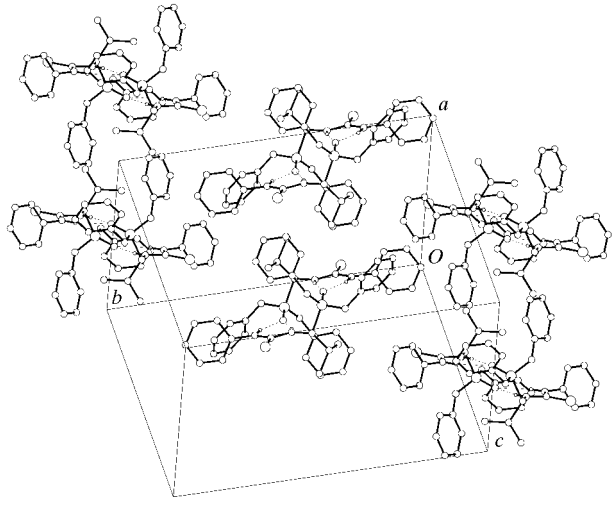


Figure 8
The crystal packing of (IV).

In both compounds (I) and (II), weak intramolecular C—H···S and C—H···O hydrogen bonds probably exist, with H···S and H···O contacts slightly less than the sum of the van der Waals radii (Taylor & Kennard, 1982). As shown in Tables 2 and 4, the geometries of these interactions are strongly bent.

Experimental

Compounds (I) and (II) were prepared according to the method of Kudzin & Stec (1978). (*N*-Phenylthioureidoalkyl)phosphonates were obtained by condensation of the appropriate aldehydes, *viz*. *N*-phenylthiourea and triphenyl phosphite. For (I), m.p. 396–398 K; ^{31}P NMR: δ 16.8 p.p.m. (AcOH/AcOD); MS/CI: $[M+1]^+$ 455 (22%), $[M+1–94]^+$ 361 (100%). For (II), m.p. 428–433 K; ^{31}P NMR: δ 16.2 p.p.m. (AcOH/AcOD); MS/CI: $[M+1]^+$ 455 (100%), $[M+1–94]^+$

361 (50%). All melting points are uncorrected. The ^{31}P NMR spectra were recorded with a Bruker 200 AC spectrometer at 81.01 MHz. The mass spectra (MS/CI) were obtained with a Finnigan MAT 75 spectrometer using the chemical ionization (isobutane) technique. The title compounds were crystallized by slow evaporation of chloroform–ethanol solvent systems (1:1).

Compound (I)

Crystal data

$C_{24}H_{27}N_2O_3PS$
M_r = 454.51
Triclinic, $P\overline{1}$
a = 10.1931 (7) Å
b = 10.5503 (5) Å
c = 11.9560 (7) Å
α = 90.932 (4)°
β = 103.252 (5)°
γ = 101.923 (5)°
V = 1221.78 (12) Å^3
Z = 2
D_x = 1.235 Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 6268 reflections
θ = 1.8–25.8°
μ = 0.23 mm^{-1}
T = 293 (2) K
Prism, colourless
0.45 × 0.20 × 0.17 mm

Data collection

Kuma KM-4 CCD area-detector diffractometer
ω scans
12 829 measured reflections
4288 independent reflections
2883 reflections with $I > 2\sigma(I)$
R_{int} = 0.034
θ_{max} = 25°
$h = -12 \rightarrow 10$
$k = -12 \rightarrow 12$
$l = -14 \rightarrow 14$

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)]$ = 0.049
$wR(F^2)$ = 0.153
S = 1.08
4288 reflections
307 parameters
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0833P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 0.38 e Å^{-3}
$\Delta\rho_{min}$ = −0.23 e Å^{-3}

Table 1
Selected geometric parameters (Å, °) for (I).

S1—C1	1.676 (3)	C2—P1	1.802 (3)
N1—C1	1.348 (3)	P1—O1	1.4673 (18)
N1—C11	1.418 (3)	P1—O3	1.568 (2)
N2—C1	1.348 (3)	P1—O2	1.5800 (19)
N2—C2	1.455 (3)		
C1—N1—C11	125.1 (2)	O1—P1—O3	114.06 (11)
C1—N2—C2	125.7 (2)	O1—P1—O2	115.05 (10)
N2—C1—N1	113.1 (2)	O3—P1—O2	103.78 (11)
N2—C1—S1	123.8 (2)	O1—P1—C2	115.25 (12)
N1—C1—S1	123.11 (18)	O3—P1—C2	105.40 (11)
N2—C2—P1	106.35 (16)	O2—P1—C2	101.83 (11)
C2—N2—C1—S1	3.2 (4)	C11—N1—C1—S1	−3.0 (4)

Table 2
Hydrogen-bonding geometry (Å, °) for (I).

D—H···A	D—H	H···A	D···A	D—H···A
N1—H1···O1^{i}	0.84 (2)	2.13 (2)	2.917 (3)	154 (2)
N2—H2···O1^{i}	0.82 (2)	2.15 (2)	2.915 (3)	156 (2)
C2—H201···S1	0.98	2.62	3.138 (2)	113
C3—H301···O2	0.97	2.59	3.062 (4)	110

Symmetry code: (i) $-x, -y, -z$.

Compound (II)

Crystal data

$C_{24}H_{27}N_2O_3PS$
M_r = 454.51
Monoclinic, $P2_1/c$
a = 9.9402 (4) Å
b = 16.7505 (6) Å
c = 14.1979 (5) Å
β = 91.973 (3)°
V = 2362.60 (15) Å^3
Z = 4
D_x = 1.278 Mg m^{-3}
Mo $K\alpha$ radiation
Cell parameters from 11 020 reflections
θ = 1.9–26.9°
μ = 0.23 mm^{-1}
T = 293 (2) K
Prism, colourless
0.45 × 0.32 × 0.25 mm

Data collection

Kuma KM-4 CCD area-detector diffractometer
ω scans
Absorption correction: numerical (*X-RED*; Stoe & Cie, 1999)
T_{min} = 0.901, T_{max} = 0.950
14 062 measured reflections
4148 independent reflections
3184 reflections with $I > 2\sigma(I)$
R_{int} = 0.024
θ_{max} = 25°
$h = -11 \rightarrow 11$
$k = -19 \rightarrow 19$
$l = -16 \rightarrow 16$

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)]$ = 0.045
$wR(F^2)$ = 0.132
S = 1.16
4148 reflections
320 parameters
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0682P)^2 + 0.0422P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$
$\Delta\rho_{max}$ = 0.32 e Å^{-3}
$\Delta\rho_{min}$ = −0.28 e Å^{-3}

Table 3
Selected geometric parameters (Å, °) for (II).

S1—C1	1.664 (2)	C2—P1	1.808 (2)
C1—N1	1.347 (3)	P1—O1	1.4667 (14)
C1—N2	1.353 (3)	P1—O3	1.5668 (17)
N1—C11	1.431 (3)	P1—O2	1.5758 (16)
N2—C2	1.450 (3)		
N1—C1—N2	112.66 (19)	O1—P1—O3	113.79 (9)
N1—C1—S1	123.24 (17)	O1—P1—O2	115.23 (9)
N2—C1—S1	124.10 (17)	O3—P1—O2	102.97 (10)
C1—N1—C11	125.4 (2)	O1—P1—C2	116.82 (10)
C1—N2—C2	125.10 (19)	O3—P1—C2	104.85 (10)
N2—C2—P1	106.53 (14)	O2—P1—C2	101.42 (9)
S1—C1—N1—C11	−3.4 (3)	S1—C1—N2—C2	0.2 (3)

Table 4
Hydrogen-bonding geometry (Å, °) for (II).

D—H···A	D—H	H···A	D···A	D—H···A
N1—H1···O1^{ii}	0.82 (2)	2.20 (2)	2.974 (2)	155 (2)
N2—H2···O1^{ii}	0.83 (2)	2.14 (2)	2.932 (2)	159 (2)
C2—H201···S1	0.98	2.59	3.126 (2)	115
C3—H301···O2	0.98	2.56	3.027 (3)	109

Symmetry code: (ii) $1-x, 1-y, 1-z$.

During the refinement of (I), two methyl atoms, C5 and C6, revealed very anisotropic atomic displacement parameters, so two sets of split sites were introduced for these atoms. In the subsequent refinement, the site-occupation factors refined to 0.673 (9) and

Table 5
Comparison of unit-cell parameters (Å, °) for compounds (I)–(IV).

	Space group	*a*	*b*	*c*	*α*	*β*	*γ*
(I)	$P\overline{1}$	10.1931 (7)	10.5503 (5)	11.9560 (7)	90.932 (4)	103.252 (5)	101.923 (5)
(II)	$P2_1/c$	9.9402 (4)	16.7505 (6)	14.1979 (5)	90	91.973 (3)	90
(III)	$P\overline{1}$	9.753 (1)	10.069 (1)	12.255 (1)	98.17 (1)	103.37 (1)	111.63 (1)
(IV)	$P2_1/c$	10.061 (1)	20.561 (1)	13.035 (2)	90	122.71 (1)	90

0.327 (9) for C5*A*/C6*A* and C5*B*/C6*B*, respectively. Bond-length restraints were applied to all C—C bonds involving the disordered atoms. The atoms of the C21–C26 phenyl ring of (II) were disordered. Two components of the disorder were modelled, using rigid planar hexagons for the phenyl rings. Refinement of the site-occupation factors of the disordered atoms indicated that the two conformations were approximately equally occupied. Subsequently, the occupancies of the disordered atoms were fixed at 0.5 and similarity restraints were applied to the atomic displacement parameters of those disordered atoms that were within 1.7 Å of each other. The distances between atom pairs O2/C21*A* and O2/C21*B* were restrained to be equal, with an effective s.u. of 0.003 Å. In both compounds, the amide H atoms were clearly revealed in the difference maps. Their atomic coordinates were refined with the N—H distances restrained to a common value, while their U_{iso} values were refined freely. All other H atoms were placed in geometrically idealized positions, with C—H distances in the range 0.93–0.98 Å, and constrained to ride on their parent atoms, with $U_{iso}(H) = 1.2U_{eq}(C)$ [or $1.5U_{eq}(C)$ for the methyl groups]. Collected reflections with 2θ above 50° were omitted because of their poor quality.

For both compounds, data collection: *CrysAlis CCD* in *KM*-4 *CCD Software* (Kuma Diffraction, 2001); cell refinement: *CrysAlis CCD*; data reduction: *CrysAlis RED* in *KM*-4 *CCD Software*; program(s) used to solve structure: *SHELXS*97 (Sheldrick, 1997); program(s) used to refine structure: *SHELXL*97 (Sheldrick, 1997); molecular graphics: *PLATON* (Spek, 1998); software used to prepare material for publication: *PARST*97 (Nardelli, 1996).

This work was financially supported by the University of Łódź (grant No. 505/251 2002).

Supplementary data for this paper are available from the IUCr electronic archives (Reference: LN1150). Services for accessing these data are described at the back of the journal.

References

Allen, F. H. (2002). *Acta Cryst.* B**58**, 380–388.
Allen, F. H., Kennard, O., Watson, D. G., Brammer, L., Orpen, A. G. & Taylor, R. (1987). *J. Chem. Soc. Perkin Trans.* 2, pp. S1–19.
Bernstein, J., Davis, R. E., Shimoni, L. & Chang, N.-L. (1995). *Angew. Chem. Int. Ed. Engl.* **34**, 1555–1573.
Chęcińska, L., Małecka, M., Olszak, T. A. & Kudzin, Z. H. (2001*a*). *Acta Cryst.* E**57**, o1213–o1215.
Chęcińska, L., Małecka, M., Olszak, T. A. & Kudzin, Z. H. (2001*b*). *Acta Cryst.* E**57**, o1216–o1218.
Fábián, L. & Kálmán, A. (1999). *Acta Cryst.* B**55**, 1099–1108.
Kudzin, Z. H. & Stec, W. J. (1978). *Synthesis*, pp. 469–472.
Kuma Diffraction (2001). *CrysAlis CCD* and C*rysAlis RED* (Versions 1.169) in *KM*-4 *CCD Software* (Version 1.169). Kuma Diffraction, Wrocław, Poland.
Nardelli, M. (1996). *J. Appl. Cryst.* **29**, 296–300.
Sheldrick, G. M. (1997). *SHELXS*97 and *SHELXL*97. University of Göttingen, Germany.
Spek, A. L. (1998). *PLATON*. University of Utrecht, The Netherlands.
Stoe & Cie (1999). *X-RED*. Version 1.18. Stoe & Cie, Darmstadt, Germany.
Taylor, R. & Kennard, O. (1982). *J. Am. Chem. Soc.* **104**, 5063–5070.