

nitroadamantane (George & Gilardi, 1983), and are near ideal values for the cage. Bond angles for the cage atoms do show some distortion; the average angle about the tertiary carbons is $110.2(8)^\circ$, while the average angle about the secondary carbons is $108.0(1.2)^\circ$. The average C—C distance is 1.524 \AA ; in the previously cited compounds it is 1.533 , 1.525 and 1.525 \AA , respectively, while in the low-temperature form of adamantane (Donohue & Goodman, 1967), it is 1.536 \AA .

One of the H atoms from each of the amido groups participates in a weak hydrogen bond. The hydrogen-bond parameters are $N(1)\cdots O(3'B) = 3.190(7)$, $H(1NB)\cdots O(3'B) = 2.34(5) \text{ \AA}$, $N-H\cdots O = 163(3)^\circ$ and $N(1')\cdots O(7A) = 3.140(7)$, $H(1NC)\cdots O(7A) = 2.43(5) \text{ \AA}$, $N-H\cdots O = 133(3)^\circ$, respectively, *via* symmetry operations $(x - 0.5, 0.5 - y, z - 0.5)$ and $(x + 0.5, 0.5 - y, z + 0.5)$.

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Structure of 4-Methoxy-2,6-dimethylbenzamide

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Abstract. $C_{10}H_{13}NO_2$, $M_r = 179.22$, m.p. 439–440 K, monoclinic, $P2_1/c$, $a = 5.008(4)$, $b = 6.624(3)$, $c = 29.813(13) \text{ \AA}$, $\beta = 93.03(6)^\circ$, $V = 988(1) \text{ \AA}^3$, $Z = 4$, $D_m = 1.208$, $D_x = 1.205 \text{ Mg m}^{-3}$, $\lambda(\text{Mo } K\alpha) = 0.7107 \text{ \AA}$, $\mu = 0.079 \text{ mm}^{-1}$, $F(000) = 384$, $T = 293 \text{ K}$, final $R = 0.052$ for 1614 independent reflections with $F > 3\sigma(F)$. The carbamoyl group is rotated by $56.7(1)^\circ$ with respect to the benzene ring plane. Molecular-orbital calculations yield dihedral angles of 72.4 and 32.3° for the isolated molecules of the title compound and of the parent 4-methoxybenzamide, respectively. In the crystal the molecules are linked in endless chains by hydrogen bonds involving the carbamoyl group.

Introduction. A recent ^{13}C NMR study (Dell'Erba, Mele, Novi, Petrillo, Sancassan & Spinelli, 1990) has shown the existence of a linear correlation between the carbonyl-carbon chemical shifts of 4-*X*-benzamides and 2,6-dimethyl-4-*X*-benzamides, in spite of an expected larger steric inhibition to conjugation between the CONH_2 group and the ring in

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2,6-dimethyl derivatives. To confirm the latter point and to assist in the interpretation of the observed behaviour, an X-ray crystal structure determination of the title compound (1) together with molecular-orbital calculations on both (1) and the 2,6-unsaturated derivative (2) have been performed.

Experimental. Transparent crystals were obtained from an ethyl acetate solution. A prismatic crystal of dimensions $0.38 \times 0.45 \times 0.22 \text{ mm}$ was used to collect data on a Nonius CAD-4 diffractometer with graphite-monochromatized $\text{Mo } K\alpha$ radiation, ω -scan mode, scan width 1.8° , scan speed $1.2\text{--}5^\circ \text{ min}^{-1}$, θ range $2.5\text{--}27.5^\circ$; unit cell from 25 reflections, $16.7 < \theta < 19^\circ$, least-squares refinement; max. $(\sin\theta)/\lambda = 0.65 \text{ \AA}^{-1}$; 4668 reflections collected with h 0 to 6, k -8 to 8, l -38 to 38, for a total of 2275 independent reflections; two check reflections monitored every hour to test the crystal stability, and eight to test the crystal orientation; no absorption correction applied ($\mu V_s^{1/3} = 0.026$; V_s = volume of the crystal sample); $P2_1/c$ from systematic absences; 1614

Table 1. Heavy-atom positional parameters ($\times 10^4$) and equivalent isotropic thermal parameters ($\text{\AA}^2 \times 10^4$)
$$U_{eq} = (1/3) \sum_i \sum_j U_{ij} a_i^* a_j^* a_i \cdot a_j$$

	x	y	z	U_{eq}
C(1)	3916 (3)	1968 (3)	4004 (1)	425 (5)
C(2)	4979 (4)	2681 (3)	3610 (1)	493 (6)
C(3)	4463 (4)	1629 (3)	3215 (1)	552 (6)
C(4)	2966 (4)	-111 (3)	3205 (1)	508 (6)
C(5)	1933 (4)	-829 (3)	3594 (1)	513 (6)
C(6)	2384 (4)	209 (3)	3998 (1)	464 (5)
C(7)	4449 (3)	3143 (3)	4428 (1)	488 (6)
C(8)	1189 (6)	-669 (4)	4408 (1)	736 (9)
C(9)	6647 (5)	4572 (4)	3593 (1)	767 (10)
C(10)	803 (6)	-2653 (4)	2754 (1)	804 (10)
N	2363 (3)	3785 (3)	4640 (1)	632 (6)
O(1)	6746 (2)	3534 (3)	4569 (1)	696 (6)
O(2)	2624 (3)	-1035 (2)	2796 (0)	698 (6)

Table 2. Selected bond distances (\AA) and angles ($^\circ$)

C(1)—C(7)	1.497 (3)	C(6)—C(8)	1.505 (3)
C(7)—N	1.319 (3)	C(4)—O(2)	1.368 (2)
C(7)—O(1)	1.231 (2)	O(2)—C(10)	1.409 (3)
C(2)—C(9)	1.509 (3)		
C(1)—C(2)—C(9)	123.1 (2)	C(1)—C(7)—N	117.5 (2)
C(3)—C(2)—C(9)	117.9 (2)	C(1)—C(7)—O(1)	121.2 (2)
C(1)—C(6)—C(8)	123.6 (2)	N—C(7)—O(1)	121.3 (2)
C(5)—C(6)—C(8)	117.2 (2)	C(3)—C(4)—O(2)	115.8 (2)
C(2)—C(1)—C(7)	118.4 (2)	C(5)—C(4)—O(2)	124.1 (2)
C(6)—C(1)—C(7)	121.3 (2)	C(4)—O(2)—C(10)	118.0 (2)

reflections with $F > 3\sigma(F)$ considered observed. Crystal structure solution by direct methods and refinement with *SHELX76* (Sheldrick, 1976); E map calculated with 415 contributions ($E > 1.2$); full-matrix anisotropic least-squares refinement on F for 13 non-H atoms; H atoms located on difference maps and included in structure-factor calculations with an isotropic temperature factor equal to U_{eq} of the bonded atom; in the final cycles, carbamoyl hydrogens H(1) and H(2) were also refined. A total of 126 parameters were refined minimizing $\sum w(\Delta F)^2$ with weights $w = [\sigma^2(F) + 0.0015F^2]^{-1}$; $R = 0.052$, $wR = 0.065$ for 1614 observed reflections, $S = 1.66$, $(\Delta/\sigma)_{max} = 0.018$, $\Delta\rho_{max} = 0.22$, $\Delta\rho_{min} = -0.23 \text{ e \AA}^{-3}$. The final atomic coordinates are given in Table 1 and selected bond distances and angles in Table 2.* Most of the geometry calculations were performed with the program *PARST* (Nardelli, 1983). Scattering factors were taken from *SHELX76*. The atom-numbering scheme is shown in Fig. 1 and the packing of molecules in the crystal in Fig. 2; the drawings were made using *ORTEP* (Johnson, 1965).

* Lists of structure factors, H-atom coordinates, anisotropic thermal parameters, bond lengths, bond angles and least-squares planes have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 53991 (14 pp.). Copies may be obtained through The Technical Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Discussion. In the crystal, couples of centrosymmetric molecules are linked in endless chains (parallel to the x axis) by hydrogen bonds involving the carbamoyl moiety (see Fig. 2 and Table 3). Besides the hydrogen bonds there are no intermolecular contacts appreciably shorter than the sum of the van der Waals radii involved (Pauling, 1960).

The molecular conformation deviates markedly from planarity. In the crystal, the C(2)—C(1)—C(7)—O(1) torsion angle is $-55.8(3)^\circ$ and the dihedral angle between the average planes of the benzene ring and the carbamoyl group is $56.7(1)^\circ$. Bond distances and bond angles are in the normal ranges (see Table 2); however, the differences between the C(1)—C(2)—C(9) and C(3)—C(2)—C(9) bond angles (5.2°) and between the C(1)—C(6)—C(8) and C(5)—C(6)—C(8) bond angles (6.4°) evidence a remarkable residual steric strain between the *ortho* methyl groups and the carbamoyl moiety. In addition both the 1...5 intramolecular contacts

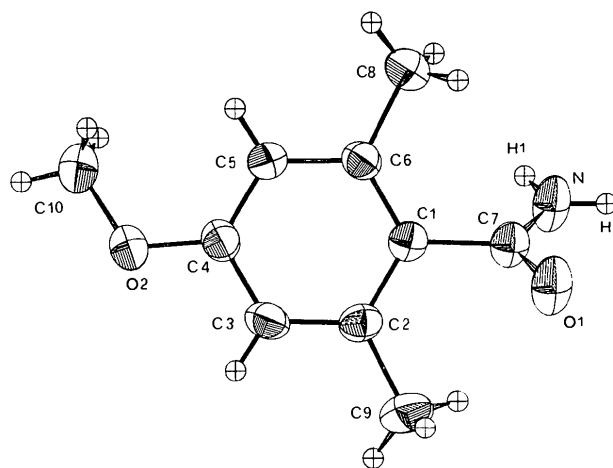


Fig. 1. Thermal ellipsoids of the title compound at the 40% probability level. Isotropic H atoms are on an arbitrary scale.

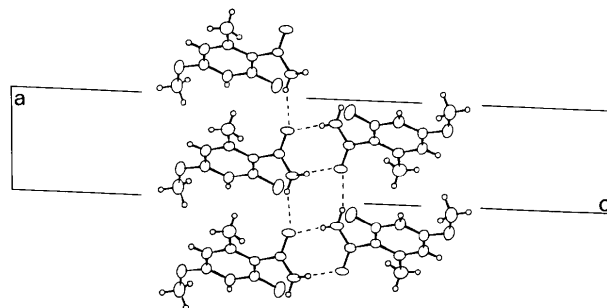


Fig. 2. Hydrogen bonds in the crystal of the title compound. For clarity, the H atoms of the C(8) methyl group are not drawn.

Table 3. *Geometry of the hydrogen bonds*

$D-H\cdots A$	$D-H$ (Å)	$H\cdots A$ (Å)	$D\cdots A$ (Å)	$D-H\cdots A$ (°)
$N-H(1)\cdots O(1)^i$	0.92 (3)	1.96 (3)	2.815 (3)	154 (2)
$N-H(2)\cdots O(1)^{ii}$	0.86 (3)	2.11 (3)	2.968 (3)	174 (2)

Equivalent positions: (i) $-1+x, y, z$; (ii) $1-x, 1-y, 1-z$.

$N\cdots C(8)$ [3.080 (3) Å] and $O(1)\cdots C(9)$ [2.988 (3) Å] are shorter by about 0.4 Å than the sum of the corresponding van der Waals radii. For the sake of comparison, in methyl 4-methoxy-2,6-dimethylbenzoate (Mugnoli, Sancassan, Novi & Petrillo, 1988) a smaller bending of the $C(2)-C(9)$ and $C(6)-C(8)$ bonds (differences, as before: 1.9 and 4.1°, respectively) corresponds to a larger rotation angle of the ester group [64.2 (1)°].

The rotation angle of the carbamoyl group with respect to the benzene ring plane is of interest, since it may show the possibility of the occurrence of through conjugation between the $CONH_2$ group and the aromatic moiety. In order to study the lack of planarity in different crystalline environments, a search on primary benzamides has been carried out using the Cambridge Structural Database system (Allen, Kennard & Taylor, 1983). After excluding disordered structures and uncorrected errors, no hits were obtained for a 2,6-dimethyl derivative. The 2,6-unsubstituted benzamides gave 26 hits with a value of the dihedral angle scattered between 1.0 and 38.4°, with an average value of 22.2° (e.s.d. of the sample 11.0°, e.s.d. of the mean 2.2°); for 17 hits in 26, the observed value ranged between 22.9 and 38.4°, and for benzamide itself 28.1°* (Blake & Small, 1972). The effect of hydrogen bonding and packing forces on molecular conformation in crystals of benzamide derivatives is especially evident in *p*-chlorobenzamide: in the α form (space group $P\bar{1}$; Taniguchi, Nakata, Takaki & Sakurai, 1978) the three independent molecules in the asymmetric unit show dihedral angles of 20.3, 30.3 and 33.8°, respectively at room temperature (17.9, 29.1 and 33.7° respectively at 153 K), whereas in the β form (space group $P2_1/a$; Hayashi, Nakata, Takaki & Sakurai, 1980) the dihedral angle is 2.1°.

Starting from the experimental results herein, the conformation of the isolated molecule of the title compound (1) was investigated by semiempirical molecular-orbital calculations within the NDDO approximation (*AM1*; Dewar, Zoebisch, Healy & Stewart, 1985) by means of the program *MOPAC* (Stewart, 1983), with the *PRECISE* keyword and full optimization. At convergence, the dihedral angle between the carbamoyl and benzene planes was 72.4°, a remarkably larger value than that found in

the crystal, where a residual intramolecular steric hindrance has however been observed (see above). On the other hand, in the calculated structure there is a noticeably smaller bending of the $C(2)-C(9)$ and $C(6)-C(8)$ bonds, the bond-angle differences involved being less than 1.4° (with the correct sign). For the parent 4-methoxybenzamide (2), the dihedral angle obtained with the same calculation protocol* (32.3°) is comparable with that shown by several 2,6-unsubstituted primary benzamides in the crystal state.

It can thus be concluded that the experimental conformation of (1) must result from a compromise between the steric strain imposed by the *ortho* methyl groups *versus* the effect of the hydrogen bonds and packing forces in the crystal, and that the calculated parameters for the isolated molecules of (1) and (2) show the marked effect of 2,6-dimethyl substitution on the rotation angle between the $CONH_2$ and aryl moieties, emphasizing the occurrence of a large steric inhibition to conjugation in 2,6-dimethyl derivatives. This result supports the rationale offered (Dell'Erba *et al.*, 1990) for the above-mentioned chemical-shift correlations, *i.e.* that the conjugation between the $CONH_2$ and aryl moieties is also scarcely important in 2,6-unsubstituted benzamides, behaviour which shows significant analogies with that previously observed for methyl benzoates (Mugnoli *et al.*, 1988; Dell'Erba, Sancassan, Novi, Petrillo, Mugnoli, Spinelli, Consiglio & Gatti, 1988).

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* Input geometry from Blake & Small (1972) for the benzamide moiety, and from the present work for the 4-methoxy group.

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* Calculated from published coordinates.

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Structure of 1-(4-Chlorophenacyl)-2-methyl-4-nitro-5-piperidinoimidazole

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Abstract. C₁₇H₁₉ClN₄O₃, *M_r* = 362.8, triclinic, *P* $\bar{1}$, *a* = 13.960 (1), *b* = 17.175 (1), *c* = 8.194 (1) Å, α = 108.14 (1), β = 104.82 (1), γ = 93.42 (1)°, *V* = 1784.0 (3) Å³, *Z* = 4, *D_x* = 1.350 g cm⁻³, λ (Cu *K* α) = 1.54178 Å, μ = 19.92 cm⁻¹, *F*(000) = 760, room temperature, *R* = 0.050 for 3012 observed reflections. The molecule possesses two basic centers, one at the imidazole N atom and the other at the piperidino N atom, yet the compound is inactive towards protonation. X-ray data and subsequent *CNDO/2* calculations relate this chemical property to electronic effects of substituents and steric effects due to molecular overcrowding.

Introduction. In our previous paper on the structure of 1-(4-chlorophenacyl)-2-methyl-5-morpholino-4-nitroimidazole, hereafter (I) (Borowiak, Wolska, Baryła & Sobiak, 1989), we presented the reasons for synthesizing 4-nitro-5-aminoimidazoles. These compounds are expected to have radiosensitizing properties in cancer therapy, but unfortunately, they are poorly water soluble. Attempts to obtain a salt of (I) failed. In this work we present the X-ray structure of 1-(4-chlorophenacyl)-2-methyl-4-nitro-5-piperidinoimidazole, hereafter (II), which is another 4-nitro-5-aminoimidazole derivative, likewise inactive in a protonation reaction.

Experimental. Crystals grown from ethanol by slow evaporation. Crystal size 0.1 × 0.1 × 0.4 mm; Syntex *P2*₁ diffractometer, graphite-monochromated Cu *K* α radiation, θ – 2θ scan mode, background and intensity of reflections calculated by peak-profile analysis (Lehmann & Larsen, 1974; Jaskólski, 1982); accurate cell parameters refined from setting angles of 15

reflections with $25.7 \leq 2\theta \leq 33.6^\circ$. 4478 unique reflections measured up to $2\theta \leq 115^\circ$ ($0 \leq h \leq 16$, $-19 \leq k \leq 19$, $-10 \leq l \leq 10$); 3012 considered observed [$I \geq 2\sigma(I)$]; *R*_{int} = 0.0184; two reference reflections monitored every 100 reflections showed no significant variation in intensity during data collection. Lp correction but no absorption correction. Structure solved by direct methods using *MULTAN80* (Main *et al.*, 1980) and refined by full-matrix least-squares methods with *SHELX76* (Sheldrick, 1976). Function minimized $\sum w(|F_o| - |F_c|)^2$, $w^{-1} = \sigma^2(F_o) + 0.0002F_o^2$, $\sigma(F_o)$ based on counting statistics. Non-H atoms refined anisotropically; the H atoms of the methyl group located from difference synthesis and kept non-refined, the other H atoms placed at their theoretical positions. Empirical isotropic extinction parameter *x* used to correct *F_c* according to $F'_c = F_c(1 - xF_c^2/\sin\theta)$, *x* converged at $7.7(9) \times 10^{-7}$. The final refinement of 452 parameters converged at *R* = 0.050, *wR* = 0.060, *S* = 2.4, (Δ/σ)_{max} = 0.06 in final cycle; largest peak in final ΔF map 0.19, largest hole $-0.34 \text{ e } \text{Å}^{-3}$; atomic scattering factors were those incorporated in *SHELX76*. Other computer programs used: *ORTEP* (Johnson, 1976), *PLUTO78* (Motherwell & Clegg, 1978) and *PARST* (Nardelli, 1983).

Discussion. Final positional parameters and *U*_{eq} values for non-H atoms are given in Table 1.† The molecule is shown in Fig. 1. Bond lengths and bond angles are listed in Table 2.

† Lists of structure factors, anisotropic thermal parameters, torsion angles, H-atom parameters and least-squares-planes data have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 53994 (23 pp.). Copies may be obtained through The Technical Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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