Acta Cryst. (1989). **B45**, 500–505

Reaction Pathways and Asymmetric Synthesis in the Solid-State Photochemistry of α-Adamantylacetophenones

By Stephen V. Evans and James Trotter

Department of Chemistry, University of British Columbia, Vancouver, BC, Canada V6T 1Y6

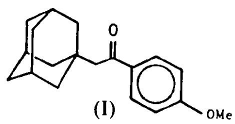
(*Received* 17 *October* 1988; *accepted* 5 *May* 1989)

Abstract

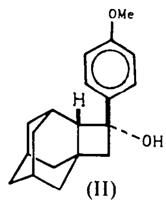
The photochemical reaction pathways of adamantylacetophenones have been studied by crystal structure analyses of α-adamantyl-p-methoxyacetophenone, one of its photoproducts and the less-symmetrical p-chloro-α-(3-methyladamantyl)acetophenone, and by correlation of the crystal and molecular structure parameters with photochemical behaviour. Crystal data are: $T = 295$ K, Mo $K\alpha_1$, $\lambda = 0{\cdot}70930$ Å; α-1-adamantyl-4-methoxyacetophenone [1-(4-methoxyphenyl)-2-(tricyclo[3.3.1.1^{3,7}]dec-1-yl)ethanone], $C_{19}H_{24}O_2$, $P2_1/n$, $a = 10{\cdot}707$ (3), $b = 22{\cdot}206$ (3), $c = 6{\cdot}505$ (2) Å, $\beta = 90{\cdot}192$ (14)°, $Z = 4$, $R = 0{\cdot}051$ for 2254 reflections; photoproduct [9-(4-methoxyphenyl)tetracyclo[6.2.0.1^{1,5}.1^{3,7}]dodecan-9-ol], $C_{19}H_{24}O_2$, $P2_12_12_1$, $a = 6{\cdot}762$ (2), $b = 6{\cdot}581$ (3), $c = 33{\cdot}26$ (3) Å, $Z = 4$, $R = 0{\cdot}062$ for 889 reflections; 4-chloro-α-1-(3-methyladamantyl)acetophenone [1-(4-chlorophenyl)-2-(3-methyltricyclo[3.3.1.1^{3,7}]dec-1-yl)ethanone], $C_{19}H_{23}ClO$, $P2_12_12_1$, $a = 6{\cdot}599$ (1), $b = 12{\cdot}028$ (1), $c = 20{\cdot}198$ (2) Å, $Z = 4$, $R = 0{\cdot}038$ for 1279 reflections. The two adamantylacetophenone derivatives have molecular dimensions and conformations similar to those of related molecules, each having a γ-H atom favourably sited for abstraction in a photochemical reaction. The photoproduct has in addition a folded four-membered ring, with the OH group in a pseudo-axial site, and *trans* relative to the adjacent ring H atom. The reaction pathways were derived by studying the motions required to produce the major products of solid-state photolysis; possible multiple routes were distinguished by study of the less-symmetrical 3-methyladamantyl derivative. The chiral $P2_12_12_1$ space group of the 3-methyl compound leads to the formation of optically active product from the achiral reactant material in the solid-state photolysis.

Introduction

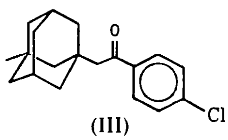
Structural and photochemical studies of α-adamantylacetophenones (Evans & Trotter, 1989) have been extended to the 4-methoxy derivative [MeO-Ad, (I)], and one of its photoproducts (II). To clarify the details of the reaction mechanisms, the investigation has been further extended to include a less-symmetrical 3-methyladamantyl derivative [ClMeAd, (III)]; this latter structure allows construction of the detailed reaction pathway. In addition, the fact that the 3-methyl derivative crystallizes in a noncentrosymmetric space group has afforded the opportunity of producting an optically active product from an achiral reactant.



(I)



(II)



(III)

Experimental

Data, measured with a Nonius CAD-4F diffractometer by the usual techniques (Evans & Trotter, 1988), are summarized in Table 1. The structures were determined by direct and Patterson methods, and refined by full-matrix least-squares procedures, with $w = 1/\sigma^2(F)$, where $\sigma^2(I) = S + 4(B_1 + B_2) + (0{\cdot}04I)^2$, S = scan, B_1 and B_2 = background counts. Scattering factors from *International Tables for X-ray Crystallography* (1974), locally written, or locally modified versions of standard computer programs (Evans & Trotter, 1988). For the 3-methyladamantyl compound, refinement of the enantiomorphic structure ($\Delta f''$ for Cl = 0·16) did not give significantly different R factors. Details of the refinements are in Table 1.

Discussion

Final positional parameters are in Table 2, bond lengths and angles in Table 3, and other data have

0108-7681/89/050500-06$03.00

Table 1. *Crystal data, and data-collection and refinement parameters*

Compound	MeO-Ad	Photoproduct	Cl-MeAd
Formula	$C_{19}H_{24}O_2$	$C_{19}H_{24}O_2$	$C_{19}H_{23}ClO$
M_r	284·40	284·40	302·84
Dimensions (mm)	0·40 × 0·33 × 0·24	0·25 × 0·25 × 0·25	0·20 × 0·35 × 0·35
Crystal system	Monoclinic	Orthorhombic	Orthorhombic
Space group	$P2_1/n$	$P2_12_12_1$	$P2_12_12_1$
a (Å)	10·707 (3)	6·762 (2)	6·599 (1)
b (Å)	22·206 (3)	6·581 (3)	12·028 (1)
c (Å)	6·505 (2)	33·26 (3)	20·198 (2)
β (°)	90·192 (14)		
V (Å^3)	1546·6 (6)	1480·1 (2)	1603·2 (5)
Z	4	4	4
D_x (g cm^{-3})	1·221	1·276	1·254
$F(000)$	616	616	648
μ(Mo) (cm^{-1})	0·7	0·8	2·3
Reflections for cell parameters			
Number	25	24	25
θ range (°)	18–25	10–18	15–22
Intensity measurements			
θ_{max} (°)	27·5	25·0	27·5
ω scan, a	1·00	1·20	0·80
$(a + b\tan\theta)$° b	0·35	0·35	0·35
Scan speeds (° min^{-1})	0·8–6·7	1·1–6·7	1·4–10
h	0 → 13	0 → 8	0 → 8
k	0 → 28	0 → 7	0 → 15
l	−8 → 8	0 → 39	0 → 26
Total unique reflections	3541	1544	2132
Reflections with $I > 3\sigma(I)$	2254	889	1279
%	63·7	57·6	60·0
Structure refinements			
No. of parameters*	190 (286)	190 (194)	190 (282)
Data/parameter ratio*	11·9 (7·9)	4·7 (4·6)	6·7 (4·5)
Δ/σ mean	0·001	0·005	0·003
maximum	0·007	0·08	0·049
$\Delta\rho$ (e Å^{-3})	±0·25	±0·25	±0·20
R [$I \geq 3\sigma(I)$]	0·051	0·062	0·038
wR	0·073	0·076	0·037
S	2·66	2·15	1·37
R (all data)	0·087	0·107	0·111

* Numbers in brackets include refined H-atom parameters.

been deposited.* The MeO-Ad and Cl-MeAd molecules (Fig. 1) each contain an adamantyl group with normal bond lengths and angles; for the two structures, C—C = 1·515–1·546 (3–6), mean 1·531 Å, C—C—C = 107·5–112·5 (2–4), mean 109·6°. The aromatic rings show some deviations from exact planarity (χ^2 = 40 and 37), but the maximum atomic displacements from a mean plane of 0·010 (2) and 0·013 (4) Å are not of any chemical significance; C—C = 1·363–1·397 (3–6), mean 1·383 Å, C—C—C = 117·8–122·3 (2–4), mean 120·0°, C—O = 1·370 (3), O—CH_3 = 1·416 (4) and C—Cl = 1·746 (4) Å. The carbonyl group is almost coplanar with the aromatic ring in MeO-Ad (angle = 4°), but is rotated out of the ring plane by 23° in Cl-MeAd.

The conformations of the central regions of the two adamantylacetophenone molecules are similar to each other, and to those of the previously studied analogues (Evans & Trotter, 1989). The torsion angle

* Lists of anisotropic thermal parameters, hydrogen positions, bond lengths and angles involving H atoms, torsion angles, and structure factors, and packing diagrams have been deposited with the British Library Document Supply Centre as Supplementary Publication No. SUP 51880 (53 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 2. *Final positional (fractional × 10^4; for Cl × 10^5) and equivalent isotropic thermal parameters ($U \times 10^3$ Å^2), with standard deviations in parentheses*

	x	y	z	U_{eq}*
MeO-Ad				
C(1)	9491 (2)	745 (1)	6515 (3)	47
C(2)	10211 (2)	843 (1)	4774 (4)	53
C(3)	11497 (2)	818 (1)	4849 (4)	56
C(4)	12084 (2)	681 (1)	6703 (4)	55
C(5)	11387 (3)	583 (1)	8459 (4)	63
C(6)	10106 (3)	622 (1)	8338 (4)	57
C(7)	8093 (2)	731 (1)	6525 (4)	54
C(8)	7335 (2)	846 (1)	4607 (4)	51
C(9)	6816 (2)	1489 (1)	4327 (3)	36
C(10)	6135 (2)	1712 (1)	6264 (3)	41
C(11)	5578 (2)	2337 (1)	5902 (3)	43
C(12)	4649 (2)	2312 (1)	4120 (3)	49
C(13)	5328 (2)	2104 (1)	2182 (3)	46
C(14)	6371 (2)	2550 (1)	1673 (3)	46
C(15)	7298 (2)	2571 (1)	3450 (3)	41
C(16)	7855 (2)	1943 (1)	3814 (3)	38
C(17)	5881 (2)	1483 (1)	2536 (3)	44
C(18)	6637 (2)	2778 (1)	5414 (3)	45
C(19)	13997 (4)	486 (2)	8469 (7)	99
O(1)	7544 (2)	615 (1)	8115 (3)	87
O(2)	13360 (2)	646 (1)	6637 (3)	77
Photoproduct				
C(1)	9019 (12)	1526 (13)	10542 (2)	30
C(2)	9125 (13)	3007 (13)	10251 (2)	34
C(3)	9037 (13)	2562 (14)	9848 (2)	37
C(4)	8795 (14)	557 (14)	9726 (2)	37
C(5)	8651 (15)	−960 (12)	10009 (2)	44
C(6)	8751 (14)	−452 (13)	10416 (2)	38
C(7)	9299 (13)	2020 (13)	10981 (2)	39
C(8)	8653 (13)	4141 (11)	11130 (2)	43
C(9)	7970 (14)	3142 (14)	11528 (3)	47
C(10)	7779 (11)	1143 (13)	11291 (2)	31
C(11)	7617 (15)	−708 (13)	11559 (3)	49
C(12)	5630 (15)	−359 (16)	11776 (3)	51
C(13)	5606 (14)	1638 (16)	12020 (2)	50
C(14)	7231 (16)	1459 (15)	12332 (2)	59
C(15)	9240 (14)	1222 (16)	12123 (2)	52
C(16)	9581 (14)	3049 (14)	11849 (3)	43
C(17)	5914 (16)	3485 (14)	11745 (2)	53
C(18)	9315 (16)	−736 (14)	11875 (2)	47
C(19)	8583 (17)	−1781 (14)	9174 (2)	57
O(1)	11310 (10)	1459 (10)	11092 (2)	46
O(2)	8711 (10)	252 (9)	9316 (1)	46
Cl-MeAd				
Cl	84587 (18)	80773 (10)	14302 (5)	66
C(1)	12487 (6)	9263 (3)	−227 (2)	40
C(2)	10482 (6)	8947 (3)	−343 (2)	42
C(3)	9283 (6)	8561 (3)	156 (2)	45
C(4)	10030 (6)	8517 (3)	786 (2)	43
C(5)	11994 (7)	8833 (3)	932 (2)	51
C(6)	13224 (7)	9189 (3)	418 (2)	48
C(7)	13921 (7)	9628 (3)	−761 (2)	46
C(8)	13145 (7)	10132 (3)	−1397 (2)	43
C(9)	12842 (5)	11406 (3)	−1370 (2)	36
C(10)	14769 (6)	11999 (3)	−1143 (2)	41
C(11)	14486 (6)	13255 (3)	−1149 (2)	47
C(12)	13989 (6)	13636 (4)	−1852 (2)	48
C(13)	12034 (5)	13076 (3)	−2092 (2)	43
C(14)	10315 (6)	13387 (4)	−1619 (2)	49
C(15)	10795 (6)	12999 (3)	−924 (2)	46
C(16)	11086 (6)	11748 (3)	−910 (2)	43
C(17)	12319 (6)	11815 (3)	−2073 (2)	41
C(18)	12734 (7)	13568 (4)	−688 (2)	57
C(19)	11551 (9)	13467 (5)	−2796 (2)	67
O(1)	15728 (4)	9556 (3)	−671 (2)	68

* $U_{eq} = \frac{1}{3}$ × trace of diagonalized U tensor.

φ_1 = C(7)—C(8)—C(9)—C(10) again corresponds to a staggered arrangement of bonds, with values of −50 and −54° in the MeO-Ad and Cl-MeAd molecules (Table 4) (the signs are of no significance, since MeO-Ad crystallizes in a centrosymmetric space group, the absolute configuration of the Cl-MeAd

Table 3. *Bond lengths* (Å) *and angles* (°), *with standard deviations in parentheses*

MeO-Ad			
C(1)—C(2)	1·389 (3)	C(9)—C(16)	1·538 (3)
C(1)—C(6)	1·381 (3)	C(9)—C(17)	1·534 (3)
C(1)—C(7)	1·498 (3)	C(10)—C(11)	1·528 (3)
C(2)—C(3)	1·379 (4)	C(11)—C(12)	1·526 (3)
C(3)—C(4)	1·392 (3)	C(11)—C(18)	1·532 (3)
C(4)—C(5)	1·384 (4)	C(12)—C(13)	1·530 (3)
C(4)—O(2)	1·370 (3)	C(13)—C(14)	1·529 (3)
C(5)—C(6)	1·376 (4)	C(13)—C(17)	1·517 (3)
C(7)—C(8)	1·508 (3)	C(14)—C(15)	1·522 (3)
C(7)—O(1)	1·218 (3)	C(15)—C(16)	1·535 (3)
C(8)—C(9)	1·544 (3)	C(15)—C(18)	1·533 (3)
C(9)—C(10)	1·540 (3)	C(19)—O(2)	1·416 (4)
C(2)—C(1)—C(6)	117·8 (2)	C(10)—C(9)—C(17)	108·3 (2)
C(2)—C(1)—C(7)	124·3 (2)	C(16)—C(9)—C(17)	108·2 (2)
C(6)—C(1)—C(7)	117·8 (2)	C(9)—C(10)—C(11)	110·6 (2)
C(1)—C(2)—C(3)	121·4 (2)	C(10)—C(11)—C(12)	109·7 (2)
C(2)—C(3)—C(4)	119·2 (3)	C(10)—C(11)—C(18)	108·9 (2)
C(3)—C(4)—C(5)	120·4 (2)	C(12)—C(11)—C(18)	110·3 (2)
C(3)—C(4)—O(2)	115·7 (2)	C(11)—C(12)—C(13)	109·0 (2)
C(5)—C(4)—O(2)	123·9 (2)	C(12)—C(13)—C(14)	109·4 (2)
C(4)—C(5)—C(6)	118·8 (2)	C(12)—C(13)—C(17)	109·6 (2)
C(1)—C(6)—C(5)	122·3 (3)	C(14)—C(13)—C(17)	109·7 (2)
C(1)—C(7)—C(8)	121·9 (2)	C(13)—C(14)—C(15)	109·3 (2)
C(1)—C(7)—O(1)	119·6 (2)	C(14)—C(15)—C(16)	110·0 (2)
C(8)—C(7)—O(1)	118·6 (2)	C(14)—C(15)—C(18)	109·9 (2)
C(7)—C(8)—C(9)	116·5 (2)	C(16)—C(15)—C(18)	108·9 (2)
C(8)—C(9)—C(10)	111·8 (2)	C(9)—C(16)—C(15)	110·3 (2)
C(8)—C(9)—C(16)	111·8 (2)	C(9)—C(17)—C(13)	111·2 (2)
C(8)—C(9)—C(17)	108·4 (2)	C(11)—C(18)—C(15)	109·0 (2)
C(10)—C(9)—C(16)	108·2 (2)	C(4)—O(2)—C(19)	117·8 (3)
Photoproduct			
C(1)—C(2)	1·375 (10)	C(9)—C(16)	1·528 (12)
C(1)—C(6)	1·380 (11)	C(9)—C(17)	1·583 (13)
C(1)—C(7)	1·506 (11)	C(10)—C(11)	1·514 (11)
C(2)—C(3)	1·375 (10)	C(11)—C(12)	1·542 (13)
C(3)—C(4)	1·390 (12)	C(11)—C(18)	1·556 (13)
C(4)—C(5)	1·374 (10)	C(12)—C(13)	1·546 (13)
C(4)—O(2)	1·380 (8)	C(13)—C(14)	1·513 (12)
C(5)—C(6)	1·397 (10)	C(13)—C(17)	1·537 (12)
C(7)—C(8)	1·544 (11)	C(14)—C(15)	1·534 (12)
C(7)—C(10)	1·567 (10)	C(15)—C(16)	1·526 (13)
C(7)—O(1)	1·457 (10)	C(15)—C(18)	1·531 (13)
C(8)—C(9)	1·548 (10)	C(19)—O(2)	1·421 (10)
C(9)—C(10)	1·538 (11)		
C(2)—C(1)—C(6)	117·4 (7)	C(10)—C(9)—C(17)	106·4 (8)
C(2)—C(1)—C(7)	121·5 (8)	C(16)—C(9)—C(17)	108·2 (6)
C(6)—C(1)—C(7)	121·0 (7)	C(7)—C(10)—C(9)	88·1 (6)
C(1)—C(2)—C(3)	122·2 (8)	C(7)—C(10)—C(11)	137·1 (7)
C(2)—C(3)—C(4)	119·5 (7)	C(9)—C(10)—C(11)	113·1 (6)
C(3)—C(4)—C(5)	119·9 (7)	C(10)—C(11)—C(12)	102·6 (7)
C(3)—C(4)—O(2)	115·5 (8)	C(10)—C(11)—C(18)	110·7 (8)
C(5)—C(4)—O(2)	124·6 (8)	C(12)—C(11)—C(18)	109·3 (7)
C(4)—C(5)—C(6)	119·1 (8)	C(11)—C(12)—C(13)	112·4 (8)
C(1)—C(6)—C(5)	121·9 (7)	C(12)—C(13)—C(14)	106·6 (8)
C(1)—C(7)—C(8)	118·0 (7)	C(12)—C(13)—C(17)	110·9 (6)
C(1)—C(7)—C(10)	118·4 (7)	C(14)—C(13)—C(17)	111·8 (8)
C(1)—C(7)—O(1)	108·0 (6)	C(13)—C(14)—C(15)	110·0 (6)
C(8)—C(7)—C(10)	86·3 (6)	C(14)—C(15)—C(16)	108·9 (8)
C(8)—C(7)—O(1)	114·3 (7)	C(14)—C(15)—C(18)	111·0 (8)
C(10)—C(7)—O(1)	110·5 (6)	C(16)—C(15)—C(18)	109·7 (6)
C(7)—C(8)—C(9)	88·6 (6)	C(9)—C(16)—C(15)	110·0 (8)
C(8)—C(9)—C(10)	87·2 (6)	C(9)—C(17)—C(13)	106·2 (8)
C(8)—C(9)—C(16)	113·7 (8)	C(11)—C(18)—C(15)	109·2 (7)
C(8)—C(9)—C(17)	126·2 (8)	C(4)—O(2)—C(19)	117·8 (6)
C(10)—C(9)—C(16)	112·6 (8)		
Cl-MeAd			
Cl—C(4)	1·746 (4)	C(9)—C(16)	1·542 (5)
C(1)—C(2)	1·397 (5)	C(9)—C(17)	1·542 (4)
C(1)—C(6)	1·394 (5)	C(10)—C(11)	1·522 (6)
C(1)—C(7)	1·501 (5)	C(11)—C(12)	1·529 (6)
C(2)—C(3)	1·363 (5)	C(11)—C(18)	1·532 (6)
C(3)—C(4)	1·367 (5)	C(12)—C(13)	1·535 (5)
C(4)—C(5)	1·382 (6)	C(13)—C(14)	1·530 (5)
C(5)—C(6)	1·388 (5)	C(13)—C(17)	1·529 (5)
C(7)—C(8)	1·511 (5)	C(13)—C(19)	1·532 (5)
C(7)—O(1)	1·209 (5)	C(14)—C(15)	1·515 (5)
C(8)—C(9)	1·546 (5)	C(15)—C(16)	1·517 (6)
C(9)—C(10)	1·529 (5)	C(15)—C(18)	1·527 (6)

Table 3 (*cont.*)

C(2)—C(1)—C(6)	118·0 (4)	C(16)—C(9)—C(17)	107·5 (3)
C(2)—C(1)—C(7)	123·8 (3)	C(9)—C(10)—C(11)	111·1 (3)
C(6)—C(1)—C(7)	118·1 (3)	C(10)—C(11)—C(12)	109·4 (3)
C(1)—C(2)—C(3)	121·2 (4)	C(10)—C(11)—C(18)	109·4 (3)
C(2)—C(3)—C(4)	119·6 (4)	C(12)—C(11)—C(18)	109·2 (3)
Cl—C(4)—C(3)	119·5 (3)	C(11)—C(12)—C(13)	110·1 (3)
Cl—C(4)—C(5)	118·7 (3)	C(12)—C(13)—C(14)	108·5 (3)
C(3)—C(4)—C(5)	121·8 (4)	C(12)—C(13)—C(17)	108·9 (3)
C(4)—C(5)—C(6)	118·2 (4)	C(12)—C(13)—C(19)	109·5 (4)
C(1)—C(6)—C(5)	121·1 (4)	C(14)—C(13)—C(17)	108·5 (3)
C(1)—C(7)—C(8)	121·0 (4)	C(14)—C(13)—C(19)	110·6 (4)
C(1)—C(7)—O(1)	119·5 (4)	C(17)—C(13)—C(19)	110·7 (3)
C(8)—C(7)—O(1)	119·4 (4)	C(13)—C(14)—C(15)	110·5 (3)
C(7)—C(8)—C(9)	114·3 (3)	C(14)—C(15)—C(16)	110·4 (3)
C(8)—C(9)—C(10)	111·5 (3)	C(14)—C(15)—C(18)	109·0 (4)
C(8)—C(9)—C(16)	112·5 (3)	C(16)—C(15)—C(18)	109·4 (3)
C(8)—C(9)—C(17)	108·3 (3)	C(9)—C(16)—C(15)	110·5 (3)
C(10)—C(9)—C(16)	108·6 (3)	C(9)—C(17)—C(13)	111·6 (3)
C(10)—C(9)—C(17)	108·3 (3)	C(11)—C(18)—C(15)	109·5 (3)

crystal studied has not been established, and the bulk materials are achiral); φ_2 = O═C(7)—C(8)—C(9) = 83 and 89°, and φ_3 = O═C(7)—C(1)—C(6) = 0 and −20° in the two compounds (Table 4).

Single crystals for X-ray study were obtained of one of the products of photolysis of α-adamantyl-4-methoxyacetophenone (after crystallization; the products are powders in the solid-state photolysis); this product is the major one in solution, and the minor one in the solid-state reaction. In the photoproduct (Fig. 1), the dimensions of the adamantyl moiety are relatively unaffected by the four-membered ring fused to it, with C—C = 1·51–1·58 (1), mean 1·54 Å, C—C—C = 102·6–113·1 (6–8), mean 109·4°. In the four-membered ring itself, bond lengths are normal, 1·538–1·567 (10), mean 1·55 Å, with C—C—C angles = 86·3–88·6 (6), mean 87·6°. The ring is distinctly folded, with bond torsion angles of ± 23·2–23·7 (6)°; the 4-methoxyphenyl substituent occupies a less-sterically hindered pseudo-equatorial position on the folded four-membered ring, with the less-bulky OH group in the pseudo-axial site [with the OH *trans* with respect to the adjacent H atom on C(10)]. The phenyl ring is planar within experimental error (χ^2 = 1·6), with normal bond lengths and angles: C—C = 1·374–1·397 (10–12), mean 1·382 Å, C—C—C = 117·4–122·2 (7–8), mean 120·0°, C—O = 1·380 (8), O—CH_3 = 1·421 (10) Å. The hydroxyl group has normal C—O and O—H bond lengths of 1·457 (10) and 0·8 (1) Å, respectively, with C—O—H = 121°. The hydroxyl group, O(1)—H, is weakly hydrogen bonded to the methoxy oxygen, O(2), of a neighbouring molecule, with O(1)···O(2) = 3·027 (12), H···O(2) = 2·35 (9) Å, O(1)—H···O(2) = 145 (4)°. These hydrogen bonds link the molecules into chains along **a**.*

Reaction pathways

Both adamantylacetophenones, MeO-Ad and Cl-MeAd, undergo the Norrish type II reaction upon

* See deposition footnote *re* packing diagram.

irradiation in solution and in the solid state (Omkaram, 1986), yielding only cyclization products (Evans & Trotter, 1989). One γ-H atom on C(10) in

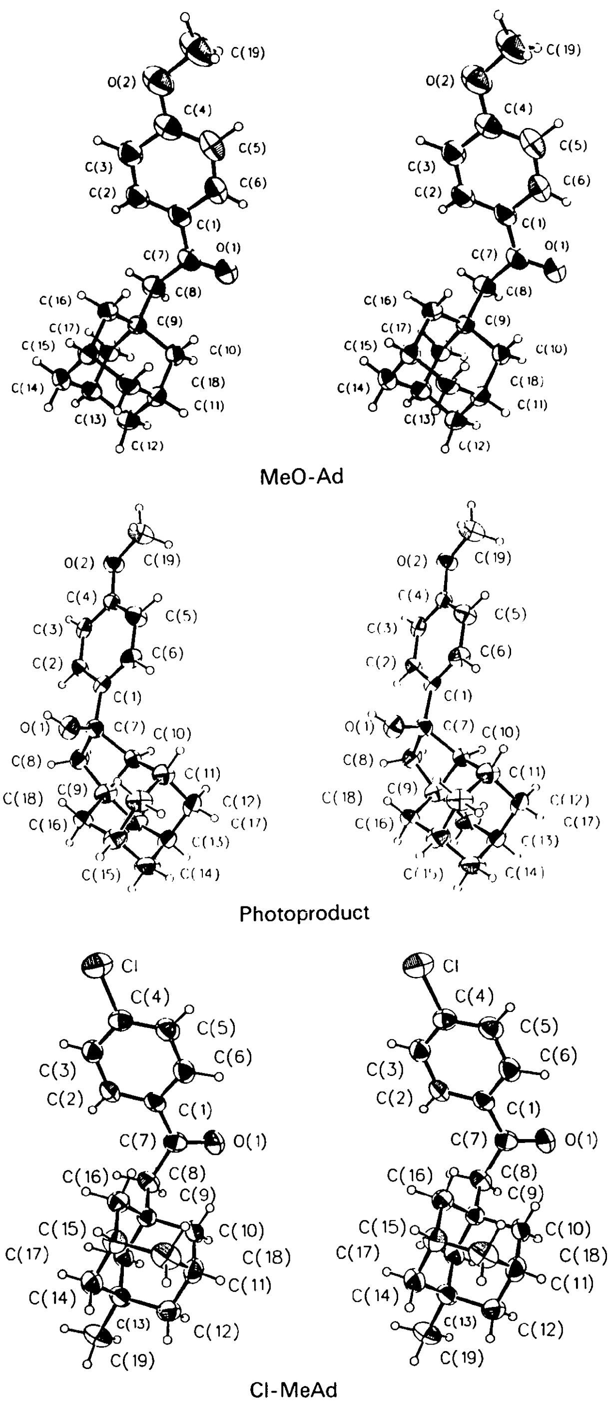


Fig. 1. Stereoviews of α-1-adamantyl-4-methoxyacetophenone (MeO-Ad), its photoproduct and 4-chloro-α-1-(3-methyladamantyl)acetophenone (Cl-MeAd – mirror image of Table 2, for direct comparison with the MeO-Ad stereodrawing; the absolute configuration of the crystal studied has not been established).

Table 4. *Molecular conformations, hydrogen-abstraction geometries, and photoproduct ratios for α-adamantylacetophenones*

	MeO-Ad		Cl-MeAd*			
Molecular conformation angles (°)						
φ_1 = C(7)—C(8)—C(9)—C(10)	−50·0		−53·8			
φ_2 = O=C(7)—C(8)—C(9)	83·3		89·4			
φ_3 = O=C(7)—C(1)—C(6)	0·2		−20·1			
Hydrogen abstraction						
Ring conformation	Chair		Chair			
d (Å)	2·67		2·71			
τ (°)	59		62			
Δ (°)	80		77			
% Cyclization	100		100			
% *cis*/*trans*-OH photoproduct						
			cis†		*trans*†	
	cis	*trans*	(1)	(3)	(2)	(4)
Benzene	28	72	12	5	40	43
Acetonitrile	34	66	15	9	35	41
Solid state	66	34	70	1	20	9

* Torsion angles for the mirror image of Table 2.
† See Fig. 3.

each adamantylacetophenone molecule is favourably sited for abstraction by oxygen in a photochemical reaction, with d, τ and Δ parameters (Table 4) close to the usual values, and chair geometries for the six-membered rings formed during the abstraction processes.

Only two photoproducts are possible for α-adamantyl-4-methoxyacetophenone (Evans & Trotter, 1989), with *cis*- and *trans*-OH groups, respectively, relative to the adjacent ring H atom. The photoproduct for which the crystal structure has been determined in the present paper is the *trans*-OH isomer; this is probably the sterically preferred product, since it has the bulky aryl substituent in the more-favourable pseudo-equatorial site of the folded four-membered ring. In solution photolysis, this *trans*-OH compound is the major (about 70%) photoproduct (Table 4); in the solid-state photolysis, however, the *cis*-OH compound is the major (66%) product. This behaviour can be rationalized on the basis of the expected geometry of the biradical intermediate formed in the photolysis reaction (Fig. 2), making the reasonable assumption that the biradical retains the basic structure of the reactant molecule. The molecule is oriented in the solid state for immediate interaction of the biradical p-orbital lobes a and b to form the *cis*-OH photoproduct, so that this can occur with minimum atomic movement. The factors governing the photoproduct ratios may be more complex, since previously studied derivatives give the *trans*-OH compound as the major product in the solid state as well as in solution, although the reactant geometries are very similar to that of MeO-Ad. In none of the derivatives do crystal packing forces seem to have a profound influence on the photoproduct ratios.

Nevertheless, it is useful to study the reaction pathway more quantitatively for MeO-Ad by examining the relevant torsion angles (Table 5). The only major movement required to form a bond with lobes a and b is a 26° change in the C(7)—C(8)—C(9)—C(10) torsion angle (from −50 to −24°), followed by a reduction of the C(7)···C(10) distance of 3·007 (12) Å to a final bond distance of about 1·57 Å (as observed for the *trans*-OH photoproduct). Also involved are changes in the a—b, φ_γ and φ_{CO} angles (Table 5) of about 40° (or some lesser amount if the four-membered ring is considered to have 'bent' bonds), 70 and 30°, respectively, but these result mainly from changes of hybridization at C(7) and C(10). The *cis*-OH photoproduct could also result from closure of lobes a' and b' (Fig. 2), but this would require much larger changes in biradical geometry: 74° (−50 to +24°) in φ_1, with 94° change in a—b angle, and a nearly 180° rotation about C(7)—C(8); this therefore seems a less-likely pathway in the solid state.

The *trans*-OH isomer (34% in the solid state) can be formed by closure of either lobes a and b' or lobes a' and b (Table 5). The former pathway involves rotation of 180° about C(7)—C(8), to bring lobe b' into the vicinity of lobe a, while the latter involves rotation about C(8)—C(9) to bring lobe a' closer to lobe b. These multiple routes, which cannot be distinguished simply on the basis of product ratios, result from the mirror symmetry of the adamantyl grouping in the biradical. To provide more detailed knowledge of these possible pathways the 3-methyladamantyl derivative was studied.

The presence of the 3-methyl group removes the mirror symmetry of the biradical intermediate, and results in six possible cyclization photoproducts (Fig. 3). Irradiation of *p*-chloro-α-(3-methyladamantyl)acetophenone in solution or in the solid state produces a mixture of four of the six possible products (Table 4). The biradical (Fig. 2) has favourable geometry for immediate closure of lobes a and b to form a more-sterically hindered *cis*-OH photoproduct (1), which is the major product (70%) of solid-state photolysis. This pathway again involves minimum atomic motion, with a 30° rotation about C(8)—C(9), and other motions similar to those described above for α-adamantyl-*p*-methoxyacetophenone. Formation of the less-sterically hindered *trans*-OH products is the next most favourable process, and involves either rotation of ~180° about C(7)—C(8) to bring lobe b' into proximity with lobe a' [to form *trans*-OH compound (2)], or rotation of ~90° about C(8)—C(9) to bring lobe a' into proximity with lobe b [to form *trans*-OH (4)]; the former of these processes appears to be more favourable in the solid-state photolysis, since (2) is the second most abundant photoproduct [20%, with only 9% of (4) (Table 4)]. Formation of the *cis*-OH compound (3) is very restricted, since it requires large motions about both central bonds to bring lobes a' and b' into proximity.

Formation of (5) and (6) (Fig. 3) is precluded in the solid state, since the corresponding γ-H atoms are not in abstractable positions, being more than 4 Å from the carbonyl O atom. In solution, product formation appears to be governed mainly by intramolecular interactions, with less-sterically hindered *trans*-OH compounds (2) and (4) being favoured (~40% of each). The absence of (5) and (6), even in solution, is probably due to steric interactions between the 3-methyl and 4-chlorophenyl groups

Table 5. *Angles* (°) *relevant to reaction pathways*

p-Orbital lobes*		*a*–*b* angle	Torsion angles† φ_1	φ_γ	φ_{CO}	Photoproduct
MeO-Ad						
a	*b*	63	−50	+93	−8	*cis*-OH‡
b	*b′*	117	−50	+93	172	*trans*-OH
a′	*b*	117	−50	−87	−8	*trans*-OH
a′	*b′*	63	−50	−87	172	*cis*-OH
Cl-MeAd§						
a	*b*	70	−54	+93	2	*cis*-OH (1)‡
a	*b′*	110	−54	+93	−178	*trans*-OH (2)
a′	*b*	110	−54	−87	2	*trans*-OH (4)
a′	*b′*	70	−54	−87	−178	*cis*-OH (3)

* See Fig. 2.

† φ_1 = C(7)—C(8)—C(9)—C(10), $\varphi_\gamma = p_\gamma$—C(10)—C(9)—C(8) = C(8)—C(9)—C(10)—C(11) − 90°, $\varphi_{CO} = p_{CO}$—C(7)—C(8)—C(9) = C(1)—C(7)—C(8)—C(9) + 90°.

‡ Major solid-state photoproducts.

§ Mirror image of Table 2.

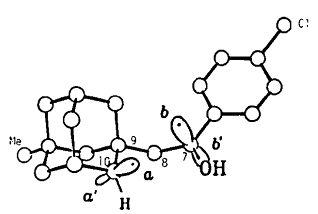


Fig. 2. Schematic drawing of the biradicals formed in the solid-state photolysis of α-1-adamantyl-4-methoxyacetophenone (omit the 3-methyl substituent, and replace the Cl substituent by OMe), and of 4-chloro-α-1-(3-methyladamantyl)acetophenone.

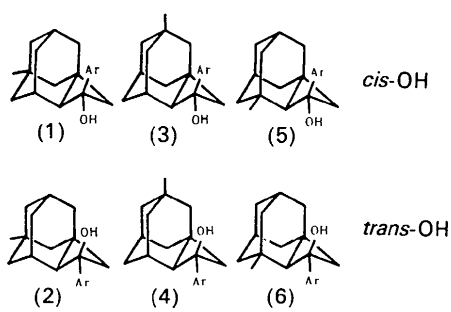


Fig. 3. Possible products in the photolysis of 4-chloro-α-1-(3-methyladamantyl)acetophenone ($Ar = ClC_6H_4$).

which prevent the close approach of the appropriate γ-H atom to O.

In conclusion, the solid-state photolyses are topochemically controlled, with minimum motion resulting in formation of the *cis*-OH photoproduct (1) (Fig. 3) *via* interaction of *p*-orbital lobes *a* and *b* (Fig. 2), while the less-sterically hindered *trans*-OH compounds [(2) and (4)] are formed in solution reactions.

Asymmetric synthesis

The crystallographic study of 4-chloro-α-(3-methyladamantyl)acetophenone indicated that the material crystallized in the chiral space group $P2_12_12_1$ (Table 1). This suggested the possibility of producing an optically active product mixture from the achiral reactant material (Evans, Garcia-Garibay, Omkaram, Scheffer, Trotter & Wireko, 1986); the important factor is that the (chance) crystallization of the achiral reactant in a chiral space group provides a chiral environment for the reactant. Products formed by photolysis in solution or in a polycrystalline aggregate show no trace of optical activity. However, when a single crystal weighing 313 mg was photolysed, the major product was the *cis*-OH compound (1), with $[\alpha]_D = -21{\cdot}6°$, and an enantiomeric excess of 80% (as determined by the use of a chiral NMR shift reagent). The lack of total stereospecificity may be due to inversion twinning in the crystal, or to disruption of the crystal lattice as the reaction proceeds.

We thank Professor J. R. Scheffer and Dr N. Omkaram for collaborative photochemical studies, the Natural Sciences and Engineering Council of Canada for financial support, and the University of British Columbia Computing Centre for assistance.

References

EVANS, S. V., GARCIA-GARIBAY, M., OMKARAM, N., SCHEFFER, J. R., TROTTER, J. & WIREKO, F. (1986). *J. Am. Chem. Soc.* **108**, 5648–5650.
EVANS, S. V. & TROTTER, J. (1988). *Acta Cryst.* **B44**, 63–72.
EVANS, S. V. & TROTTER, J. (1989). *Acta Cryst.* **B45**, 159–162.
International Tables for X-ray Crystallography (1974). Vol. IV, pp. 99–102 and 149. Birmingham: Kynoch Press. (Present distributor Kluwer Academic Publishers, Dordrecht.)
OMKARAM, N. (1986). PhD Thesis, Univ. of British Columbia, Canada.

Acta Cryst. (1989). **B45**, 505–512

Structural Study of Histamine H_2-Receptor Antagonists. Five 3-[2-(Diaminomethyleneamino)-4-thiazolylmethylthio]propionamidine and -amide Derivatives

BY TOSHIMASA ISHIDA, YASUKO IN, MITSUNOBU DOI AND MASATOSHI INOUE

Osaka University of Pharmaceutical Sciences, 2-10-65 *Kawai, Matsubara, Osaka* 580, *Japan*

AND ISAO YANAGISAWA

Central Research Laboratories, Yamanouchi Pharmaceutical Co. Ltd, No. 1–8, *Azusawa* 1-*chome, Itabashi-ku, Tokyo* 174, *Japan*

(*Received* 28 *January* 1989; *accepted* 1 *June* 1989)

Abstract

(1) N^2-Cyano-3-[2-(diaminomethyleneamino)-4-thiazolylmethylthio]propionamidine monohydrate, $C_9H_{13}N_7S_2.H_2O$, $M_r = 301{\cdot}39$, $P\bar{1}$, $a = 11{\cdot}089\ (4)$, $b = 9{\cdot}130\ (6)$, $c = 7{\cdot}033\ (5)$ Å, $\alpha = 100{\cdot}99\ (6)$, $\beta = 83{\cdot}86\ (5)$, $\gamma = 86{\cdot}80\ (7)°$, $V = 692{\cdot}9\ (6)$ Å^3, $Z = 2$, $D_m = 1{\cdot}443\ (2)$, $D_x = 1{\cdot}444$ g cm^{-3}, λ(Cu $K\alpha$) = 1·5418 Å, $\mu = 34{\cdot}86$ cm^{-1}, $F(000) = 316$, $T = 293$ K, $R = 0{\cdot}043$ for 2219 reflections. (2) 3-[2-(Diaminomethyleneamino)-4-thiazolylmethylthio]-N^2-sulfamoylpropionamidine (famotidine) hydrochloride, $C_8H_{15}N_7O_2S_3.HCl$, $M_r = 373{\cdot}90$, Cc, $a = 15{\cdot}205\ (3)$, $b = 14{\cdot}442\ (3)$, $c = 9{\cdot}262\ (1)$ Å, $\beta = 124{\cdot}00\ (5)°$, $V = 1686{\cdot}1\ (7)$ Å^3, $Z = 4$, $D_m = 1{\cdot}470\ (2)$, $D_x = 1{\cdot}473$ g cm^{-3}, μ(Cu $K\alpha$) = 56·09 cm^{-1}, $F(000) = 776$, $T = 293$ K, $R = 0{\cdot}036$ for 1411 reflections. (3) 3-[2-(Diaminomethyleneamino)-4-thiazolylmethylthio]-propionamide, $C_8H_{13}N_5OS_2$, $M_r = 259{\cdot}35$, $P2_12_12_1$, $a = 5{\cdot}472\ (1)$, $b = 18{\cdot}260\ (5)$, $c = 11{\cdot}890\ (3)$ Å, $V = 1188{\cdot}0\ (5)$ Å^3, $Z = 4$, $D_m = 1{\cdot}448\ (1)$, $D_x = 1{\cdot}450$ g cm^{-3}, μ(Cu $K\alpha$) = 39·26 cm^{-1}, $F(000) = 544$, $T = 293$ K, $R = 0{\cdot}036$ for 1260 reflections. (4) 3-{2-[Amino(methylamino)methyleneamino]-4-thiazolylmethylthio}-N^2-cyanopropionamidine, $C_{10}H_{15}N_7S_2$, $M_r = 297{\cdot}40$, $P2_1/c$, $a = 14{\cdot}235\ (5)$, $b = 5{\cdot}453\ (2)$, $c = 17{\cdot}782\ (7)$ Å, $\beta = 90{\cdot}13\ (6)°$, $V = 1380{\cdot}2\ (8)$ Å^3, $Z = 4$, $D_m = 1{\cdot}420\ (1)$, $D_x = 1{\cdot}431$ g cm^{-3}, μ(Cu $K\alpha$) =

0108-7681/89/050505-08$03.00