

The Crystal Structure of 10-Chloromethyl-2,3,9-trimethylantracene

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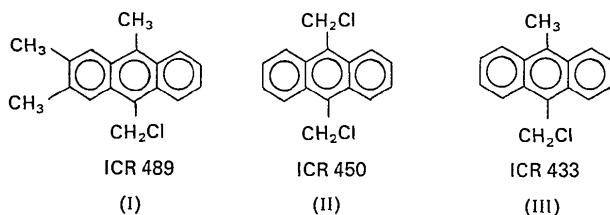
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10-Chloromethyl-2,3,9-trimethylantracene, $C_{18}H_{17}Cl$, crystallizes in the monoclinic space group $P2_1/c$ with unit-cell dimensions $a = 11.026 \pm 0.005$, $b = 14.387 \pm 0.006$, $c = 9.093 \pm 0.004$ Å, $\beta = 103.64^\circ \pm 0.02^\circ$, $Z = 4$, observed density 1.25 g.cm^{-3} , calculated density 1.27 g.cm^{-3} . The intensities of 2347 reflections were measured on an automatic diffractometer with Cu $K\alpha$ radiation by the θ - 2θ scan technique. Of these reflections 201 were below the threshold of measurement. The structure was determined by the Patterson superposition method, and atomic parameters were refined by full-matrix least-squares methods. All hydrogen atoms were located from a Fourier difference synthesis, and further refinement resulted in an R value of 0.054 for the observed data. The aromatic portion of the molecule is approximately planar. There is considerable overlap of the ring systems in the packing of the crystal and the chlorine atom of one molecule packs near the more positively charged atoms in the ring systems of other molecules.

Introduction

As part of a program of study of the structures of related antitumor agents the crystal structure of ICR 489 has been determined. This compound, for which the chemical name is 10-chloromethyl-2,3,9-trimethylantracene (I), was prepared by Peck & O'Connell (1970). The compound, shown below, is not nearly as



good an antitumor agent against Ehrlich ascites tumors in mice as is ICR 450 (II), for which the crystal structure has been determined (Gabe & Glusker, 1971), or ICR 433 (III) which has a methyl group in place of one CH_2Cl group in ICR 450. We undertook this structure determination to see what effect the additional methyl substitutions had on the crystal structure and whether we could correlate any such effects with the decreased activity of ICR 489.

Experimental

Large yellow rectangular prisms were supplied to us by Dr R. Peck of this Institute. The crystal data are given in Table 1. A crystal 0.4–0.5 mm on a side was selected for data collection on a Syntex PI automated diffractometer. The data set of 2347 reflections was measured in the θ - 2θ scan mode with monochromatized Cu $K\alpha$ radiation. Values of $\sigma(I)$ were determined from counting statistics and measured instrumental uncertainties. There were 201 reflections where $I_{\text{obs}} < 2.33 \sigma(I)$ (where I = intensity) and these were considered un-

observed. When $I \geq \sigma(I)$ the measured value of I was used to compute F , but when $I < \sigma(I)$, the value of $0.77\sigma(I)$ was used to compute F . The reflection 040 was so intense that it was remeasured, together with standard reflections to enable scaling, at a lower amplitude. The intensity data were converted to structure factors by the application of Lorentz and polarization factors and an absorption correction was applied (Johnson, 1963).

Table 1. Crystal data

ICR 489, $C_{18}H_{17}Cl$. F.W. 268.79, m.p. 141–143 °C.
$a = 11.026 \pm 0.005$ Å
$b = 14.387 \pm 0.006$
$c = 9.093 \pm 0.004$
$\beta = 103.64 \pm 0.02^\circ$
$\lambda(\text{Cu } K\alpha) = 1.5418$ Å, 25 °C. (E.s.d. values from measurements on 22 reflections.)
$D_m = 1.25 \text{ g.cm}^{-3}$ (floatation in KI solution), $D_x = 1.27 \text{ g.cm}^{-3}$.
Monoclinic, $Z = 4$.
Space group $P2_1/c$ (systematic absences $h0l$ with l odd, $0k0$ with k odd).
Crystal dimensions $0.05 \times 0.05 \times 0.04$ cm.
$\mu = 22.1 \text{ cm}^{-1}$ for Cu $K\alpha$ radiation,
$F(000) = 568$,
$\sin \theta/\lambda$ (max) = 0.60.

Structure solution and refinement

The structure was determined by application of the vector superposition method using the chlorine atom positions determined from the Patterson map. The R value with the chlorine atom alone was 0.55 and with all 19 atoms 0.41. Two cycles of block-diagonal least-squares refinement, using isotropic temperature factors, reduced the R value to 0.17. Further refinement with anisotropic thermal parameters reduced R to 0.12. A difference Fourier synthesis revealed all seventeen hydrogen atoms, and full matrix least-squares refinement of all the atoms using anisotropic temperature parameters for the heavier atoms and isotropic for the hydrogen atoms resulted in a final R value of 0.054

for observed reflections and 0.063 for all reflections. The weights used throughout the refinement procedure were those derived from the standard deviations of the reflections. The weighted *R* value was 0.064. An extinction correction was not judged to be necessary except, possibly, for the reflection 040 and therefore was not applied. The final parameters are given in Table 2 and the structure factors in Table 3.

Table 2. Final atomic parameters

Positional parameters are expressed as fractions of cell edges. Anisotropic temperature factors are expressed as

$$\exp [-\frac{1}{2}(B_{11}h^2a^{*2} + \dots + 2B_{12}hka^*b^* + \dots)]$$

and isotropic temperature factors as

$$\exp (-B \sin^2 \theta/\lambda^2)$$

with *B* values given in Å². Estimated standard deviations, determined from the inverted full matrices, are listed beside each parameter, with respect to the last decimal place given.

(a) Positional parameters for heavy atoms

	X	Y	Z
Cl(1)	0.19257 (6)	0.04085 (4)	0.23934 (7)
C(1)	0.0914 (2)	0.1412 (2)	-0.1317 (3)
C(2)	0.0194 (2)	0.1351 (2)	-0.2738 (3)
C(3)	0.0744 (2)	0.1213 (2)	-0.3955 (3)
C(4)	0.1986 (2)	0.1151 (2)	-0.3732 (2)
C(5)	0.2803 (2)	0.1208 (1)	-0.2259 (2)
C(6)	0.2242 (2)	0.1341 (1)	-0.1003 (2)
C(7)	0.3007 (2)	0.1409 (1)	0.0479 (2)
C(8)	0.4111 (2)	0.1153 (1)	-0.2032 (2)
C(9)	0.4869 (2)	0.1224 (1)	-0.0550 (2)
C(10)	0.4306 (2)	0.1347 (1)	0.0716 (2)
C(11)	0.5139 (2)	0.1404 (1)	0.2188 (2)
C(12)	0.6392 (2)	0.1363 (1)	0.2433 (2)
C(13)	0.6952 (2)	0.1237 (1)	0.1173 (2)
C(14)	0.6200 (2)	0.1176 (1)	-0.0234 (2)
C(15)	0.8350 (2)	0.1170 (2)	0.1409 (3)
C(16)	0.7207 (2)	0.1427 (2)	0.4025 (3)
C(17)	0.4704 (2)	0.1036 (2)	-0.3354 (2)
C(18)	0.2414 (2)	0.1513 (2)	0.1786 (2)

(b) Anisotropic temperature factors for heavy atoms

	B ₁₁	B ₂₂	B ₃₃	B ₁₂	B ₁₃	B ₂₃
Cl(1)	8.25 (4)	6.05 (3)	5.87 (3)	-0.89 (2)	3.55 (3)	-0.06 (2)
C(1)	4.01 (9)	5.34 (11)	6.02 (11)	0.10 (8)	0.90 (8)	0.55 (8)
C(2)	4.30 (10)	5.63 (12)	7.32 (14)	-0.30 (9)	-0.24 (10)	0.80 (10)
C(3)	5.89 (13)	6.10 (13)	5.50 (12)	-0.40 (10)	-1.05 (10)	0.24 (10)
C(4)	5.97 (12)	5.40 (11)	4.38 (10)	-0.31 (9)	0.19 (9)	-0.03 (8)
C(5)	4.58 (10)	3.84 (8)	4.12 (9)	-0.01 (7)	0.52 (7)	0.17 (7)
C(6)	4.18 (9)	3.65 (8)	4.72 (9)	0.00 (7)	0.81 (7)	0.24 (7)
C(7)	4.11 (9)	3.68 (8)	4.19 (8)	0.10 (6)	1.06 (7)	0.00 (6)
C(8)	5.04 (10)	4.20 (9)	3.92 (9)	-0.03 (7)	1.31 (7)	0.05 (7)
C(9)	4.25 (9)	3.68 (8)	4.08 (8)	-0.09 (7)	1.13 (7)	0.00 (6)
C(10)	4.05 (9)	3.56 (8)	3.97 (8)	0.12 (6)	0.88 (7)	-0.01 (6)
C(11)	4.90 (10)	4.46 (9)	3.93 (8)	0.40 (7)	0.79 (7)	-0.16 (7)
C(12)	4.68 (10)	4.11 (9)	4.78 (9)	0.25 (7)	0.16 (8)	-0.26 (7)
C(13)	3.95 (9)	3.99 (9)	5.60 (11)	-0.22 (7)	0.75 (8)	-0.03 (8)
C(14)	4.44 (10)	4.38 (9)	5.24 (10)	-0.10 (7)	1.81 (8)	-0.03 (8)
C(15)	4.01 (10)	6.66 (13)	7.56 (14)	-0.24 (9)	0.85 (9)	-0.25 (11)
C(16)	5.65 (12)	7.32 (14)	5.46 (12)	0.55 (10)	-0.56 (9)	-0.82 (10)
C(17)	6.69 (13)	6.77 (13)	4.30 (10)	0.29 (10)	2.06 (9)	-0.20 (9)
C(18)	4.61 (10)	4.75 (10)	4.86 (9)	0.22 (8)	1.43 (8)	-0.53 (7)

Table 2 (cont.)

(c) Hydrogen atoms

	X	Y	Z	B
H(1)	0.058 (1)	0.148 (1)	-0.057 (2)	4.3 (3)
H(2)	-0.062 (2)	0.132 (2)	-0.280 (3)	9.2 (6)
H(3)	0.027 (2)	0.114 (2)	-0.486 (3)	8.9 (6)
H(4)	0.226 (2)	0.107 (2)	-0.455 (2)	7.1 (5)
H(11)	0.485 (2)	0.151 (1)	0.315 (2)	6.3 (5)
H(14)	0.662 (2)	0.111 (1)	-0.103 (2)	6.2 (5)
H(151)	0.862 (2)	0.100 (2)	0.051 (2)	7.9 (6)
H(152)	0.874 (2)	0.068 (2)	0.212 (3)	7.8 (6)
H(153)	0.884 (2)	0.174 (2)	0.187 (2)	8.3 (6)
H(161)	0.773 (2)	0.084 (2)	0.430 (3)	8.2 (6)
H(162)	0.672 (3)	0.154 (2)	0.474 (3)	12.1 (8)
H(163)	0.784 (2)	0.195 (2)	0.408 (2)	8.2 (6)
H(171)	0.424 (3)	0.672 (2)	-0.405 (3)	10.1 (8)
H(172)	0.533 (3)	0.059 (2)	-0.312 (3)	10.8 (8)
H(173)	0.496 (2)	0.158 (2)	-0.383 (2)	6.7 (5)
H(181)	0.292 (2)	0.175 (1)	0.266 (2)	5.1 (4)
H(182)	0.166 (2)	0.189 (1)	0.151 (2)	6.6 (5)

Computations

The full matrix least-squares cycles of refinement were calculated on a CDC 6600 at New York University via a DCT 2000 terminal, with a modification of the program by Gantzel, Sparks, Long & Trueblood (1969). The quantity minimized was $\sum \omega |F_o| - |F_c|)^2$ with weights, ω , assigned as $1/[\sigma(F)]^2$. All other computations were made with the X-RAY 70 system (Stewart, Kundell & Baldwin, 1970) on a UNIVAC 1108 computer, also via a DCT 2000 terminal.

Scattering factors were taken from *International Tables for X-ray Crystallography* (1962) except for those for hydrogen, for which the values of Stewart, Davidson & Simpson (1965) were used. The scattering factors for chlorine were corrected for the real component of anomalous dispersion ($\Delta f' = +0.348$) (Cromer & Liberman, 1970).

Table 2 (cont.)

Table 3 (cont.)

-3.131L	1 51 -3	-1 39 -29	-1 22 14	-5 65 63	-2.14L	1 28 -21	-6 67 86	-5 81 -78		5 148 -154	-8 35 -34	D=8L	-1 45 -48
	2 131 -140	-2 56 -96	0 125 -153	-4 431 -102		0 18 -28	-5 30 -53	-4 91 -89		6 43 -42	-3 21 -24		02415 -2781
-8 40 8	3 31 31	-1 116 111	1 85 -76	-3 267 -261	-9 29 -76	1 6 -8	-4 30 -87	-3 31 -112		7 358 361	-2 54 -24		-9 20 -19
-7 93 104	4 62 82	0 133 134	2 292 286	-2 96 101	-8 10 -10	2 22 14	-3 21 24	-7 75 246		8 4 11	-1 22 23		-7 64 -12
-6 19 16	5 23 29	1 54 -51	3 152 148	-1 170 182	-7 63 60	3 24 21	-2 100 103	-1 107 95		9 14 15	0 12 17		-10 54 -10
-5 11 -16	6 14 -16	2 99 -73	4 202 197	-2 107 -107	-6 6 6	4 21 -14	-1 69 92	0 208 -218		10 10 12			-10 54 -10
-4 56 58	7 19 14	3 159 -14	5 231 -15	1 235 -244	-5 231 -227	5 5* -8	0 54 -60	6 509 -486		11 181 -190			-15 168 -165
-3 246 -231	8 29 30	4 99 101	6 10 -11	2 621 623	-3 181 185	-1.1-13L	2 24 -10	2 82 81		12 88 93			-11 185 192
-2 31 -23	9 39 34	5 174 -72	7 35 -37	3 174 185	-3 181 185		2 24 -10	2 82 81		13 11 10			-11 185 192
-1 325 161	10 49 44	6 242 -93	8 67 60	4 120 -125	-2 12 6		3 15 -13	4 242 -250		14 11 -6			-12 188 70
0 37 -14	11 59 54	7 314 -102	9 140 -11	5 168 -175	-1 12 6		4 17 18	5 72 -67		15 9 -8			-12 188 70
1 428 -47	12 69 64	8 381 -111	10 21 21	6 216 221	-2 12 6		5 27 -26	6 36 25		16 3 37			-13 191 196
2 360 -355	13 79 74	9 450 -120	11 30 -30	7 284 281	8 63 65		6 101 -106	7 284 284		17 62 59			-14 144 153
3 652 648	14 89 84	10 539 -129	12 40 -40	8 368 373	9 71 66		7 116 115	8 368 373		18 92 87			-15 144 153
4 918 907	15 99 94	11 628 -138	13 50 -50	9 456 461	10 79 74		8 232 237	9 456 461		19 121 116			-16 144 153
5 1103 -111	16 109 104	12 717 -147	14 60 -60	10 544 549	11 88 83		9 318 323	10 544 549		20 150 145			-17 144 153
6 29 30	17 119 114	13 926 -156	15 70 -70	11 632 637	12 97 92		10 404 409	11 632 637		21 179 174			-18 144 153
7 128 130	18 129 124	14 1135 -165	16 80 -80	12 720 725	13 106 101		11 490 495	12 720 725		22 208 203			-19 144 153
8 52 67	19 139 134	15 1344 -174	17 90 -90	13 808 813	14 115 110		12 576 581	13 808 813		23 237 232			-20 144 153
9 74 -78	20 149 144	16 1553 -183	18 100 -100	14 896 901	15 124 119		13 662 667	14 896 901		24 266 261			-21 144 153
10 37 -38	21 159 154	17 1762 -192	19 110 -110	15 984 989	16 133 128		14 748 753	15 984 989		25 295 290			-22 144 153

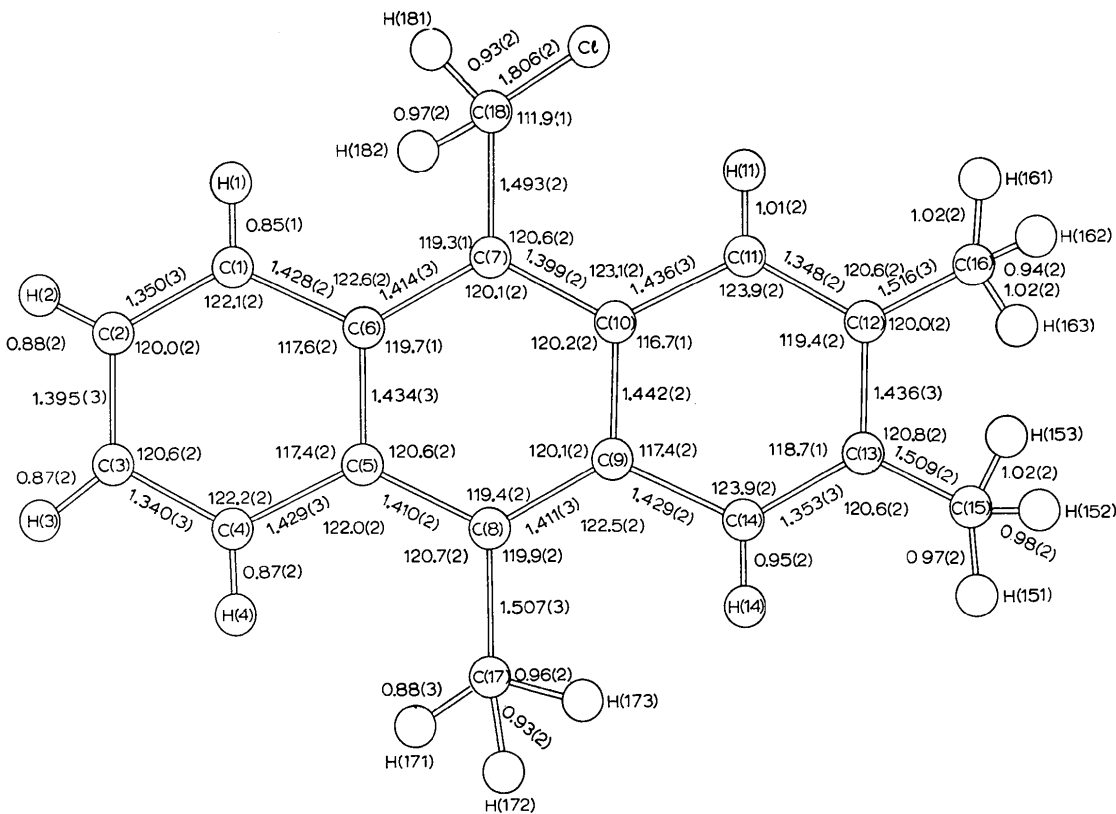


Fig. 1. Bond lengths and interbond angles in 10-chloromethyl-2,3,9-trimethylantracene. Distances are in Å and angles in degrees and estimated standard deviations are given in parentheses with respect to the last digit listed. Angles involving hydrogen atoms are not given because e.s.d. values are large (~1-2°). The measured angles are: tetrahedral, maximum 116°, minimum 92° (next 104°), average 109°; trigonal, maximum 122°, minimum 112°, average 119°.

in the central ring (1.399–1.442 Å) are longer than expected for a truly aromatic system. The only significant difference between distances in this compound and those in ICR 450 is the lengthening of the bond C(12)–C(13) between two methyl groups (1.436 Å compared with 1.397 Å in ICR 450). The angles in this area of the molecule are slightly distorted, probably a result of steric hindrance between the two adjacent methyl groups C(15) and C(16). The internal angles in the ring are smaller at C(12) and C(13) and larger at C(11) and C(14) than for corresponding angles in the unsubstituted ring in this compound and in ICR 450.

The carbon–chlorine bond is long, 1.806 Å, similar to that in ICR 450 (1.810 Å). The distance C(7)–C(18) of 1.493 Å is shorter than the value of 1.507 in ICR 450 and 1.506 Å in 1,8-dichloro-9-methylantracene (Dellaca, Penfold & Robinson, 1969) indicating some double bond character, possibly resulting in a slight positive charge on C(18). The long C–Cl bond may be a result of this, *i.e.* it may indicate a contribution of the form =C⁺H₂Cl[−] to the structure as for ICR 450. The molecule is not precisely symmetrical, the distances from chlorine to C(1) and H(1), 3.598 and 3.155 Å, being shorter than those to C(11) and H(11), 3.864 and 3.510 Å. Thus the chlorine atom is inclined towards the side of the molecule that does not contain the two methyl groups. This is evident in Fig. 2(a) and (b) which are ORTEP plots (Johnson, 1965) viewed perpendicular to and along the plane of the molecule.

The molecule as a whole, except for the hydrogen atoms of the methyl and methylene groups and the chlorine atom, is almost planar, the angle between the planes of the two outer rings being 1.2°. Each ring separately is planar within 1.7 e.s.d.. The maximum deviation in the ring system (*i.e.* excluding C(15), C(16), C(17), C(18), and Cl with deviations 0.010, −0.002, 0.020, −0.048 and −1.731 Å) is 0.018 Å for C(2).

The molecular overlap is shown in Fig. 3. The molecular planes are roughly perpendicular to the *y* axis and lie at $y = \frac{1}{8}, \frac{3}{8}, \frac{5}{8}$ and $\frac{7}{8}$, explaining the high intensity of the reflection 040. There is considerable overlap of ring systems, a very different situation from that in ICR 450 where there is no overlap. In ICR 450 there is a short C...Cl distance, between different molecules, of 3.46 Å. Similarly, in 9-ethyl-10-bromoanthracene (Hauw, 1960) there is a short Br...C distance. In ICR 489 there are also short Cl...C packing distances with Cl...C(2'') = 3.51 Å and Cl...C(4') = 3.67 Å indicating possible slight residual positive charges on C(2) and C(4). It seems that the packing in ICR 489 is a consequence of the slightly negatively charged chlorine atom being attracted to these slightly positively charged areas in the unsubstituted aromatic ring. The chlorine atom is surrounded by hydrogen atoms as shown in Table 4. The carbon, C(18), which might have a possible alkylating function, lies 3.39 Å from C(5^{vi}) and 3.41 Å from C(4^{vi}) of another molecule, but this is probably because it is constrained in this

position as a result of its attachment to the chlorine atom.

Table 4. Surroundings of the chlorine atom

	Cl...H	Cl...C	<Cl...H-C
H(4 ⁱ)	2.88 Å	3.667 Å	151°
H(2 ⁱⁱ)	2.94	3.509	124
H(14 ⁱⁱⁱ)	3.14	3.903	139
H(15 ⁱⁱⁱ)	3.27	4.088	143
H(17 ⁱⁱⁱ)	3.27	4.167	162
H(16 ^{iv})	3.45	4.126	126
H(15 ^v)	3.49	3.985	114

Designations with respect to the parameters in Table 2 and the text.

i	<i>x</i> ,	<i>y</i> ,	1 + <i>z</i>
ii	− <i>x</i> ,	− <i>y</i> ,	− <i>z</i>
iii	1 − <i>x</i> ,	− <i>y</i> ,	− <i>z</i>
iv	1 − <i>x</i> ,	− <i>y</i> ,	1 − <i>z</i>
v	<i>x</i> − 1,	<i>y</i> ,	<i>z</i>
vi	<i>x</i> ,	$\frac{1}{2}$ − <i>y</i> ,	$\frac{1}{2}$ + <i>z</i>

The molecule as a whole, or minus the chlorine and two methyl groups, does not behave as a rigid body (Schomaker & Trueblood, 1968; Trueblood, 1970). The root-mean-square difference between observed and

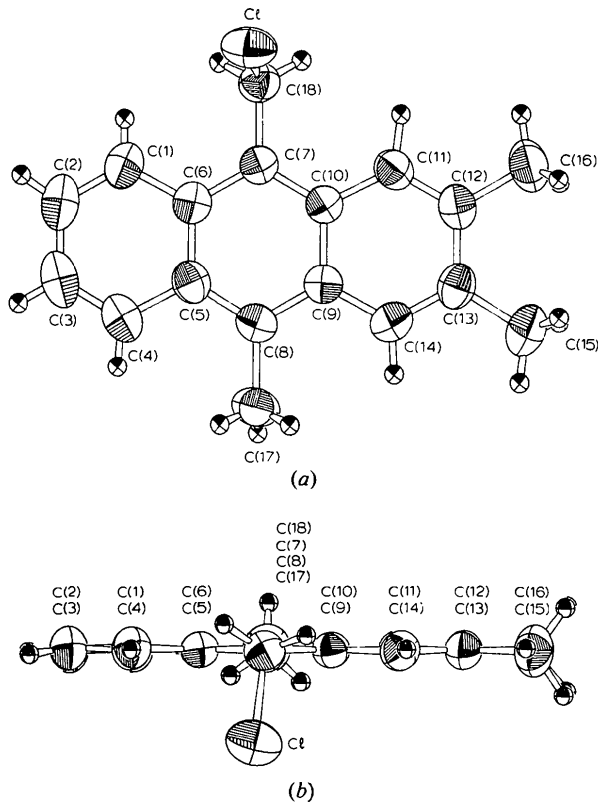


Fig. 2(a) ORTEP plot of thermal ellipsoids viewed perpendicularly to the plane of the molecule. Note the asymmetry of the chlorine position. (b) ORTEP plot of thermal ellipsoids viewed along the plane of the molecule. Note the planarity of the ring system and the asymmetry of the chlorine position.

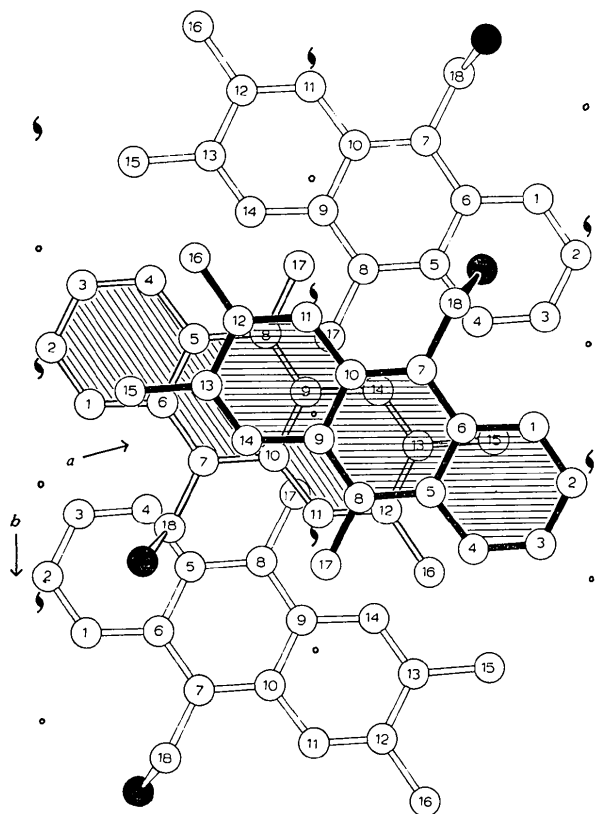


Fig. 3. Molecular overlap in the crystal structure.

calculated values of U_{ij} is 0.01 \AA^2 . The value for ICR 450 was 0.003 \AA^2 .

While both compounds appear to be good alkylating agents they pack quite differently in the crystalline state. The overlap of ring systems in ICR 489 may possibly be due to greater charge localization in the

aromatic rings while the lack of overlap of ring systems in ICR 450 may be a result of steric factors since there are two alkylating groups per molecule. We are presently trying to grow crystals of ICR 433 that are large enough for a structure determination.

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