

# (Chloromethyl)pentacarbonylmanganese(I): a crystal structure with a non-crystallographic centre of symmetry

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**Abstract** There are two molecules in the asymmetric unit of the  $P2_1/c$  unit cell of  $\text{ClCH}_2\text{Mn}(\text{CO})_5$ , the first halomethyl complex of manganese to be structurally determined. The molecules are crystallographically independent, despite an apparent local centre of symmetry. The average bond parameters include  $\text{Mn}-\text{C}_{\text{alkyl}}$  2.128(8) Å,  $\text{C}-\text{Cl}$  1.811(8) Å and  $\text{Mn}-\text{C}-\text{Cl}$  116.4(4)°.

**Keywords** Chloromethyl · Manganese carbonyl · Crystal structure · Non-crystallographic symmetry

## Introduction

Haloalkyl complexes of transition metals  $\text{ClCH}_2\text{ML}_n$  are useful in the synthesis of other derivatives and are of interest as substrates for  $\alpha$ -elimination of  $\text{CH}_2$  fragments, and for preparations of methylene compounds [1]. Structures of  $\text{ClCH}_2$  derivatives of chromium [2], iron [3],

cobalt [4] and zinc [5] have been reported for the 3d elements, but none previously for manganese. Only four earlier X-ray structures of  $\text{ClCH}_2$  derivatives of metal carbonyls have appeared, namely  $\text{ClCH}_2\text{Co}(\text{CO})_3\text{PPh}_3$  [4a],  $\text{ClCH}_2\text{CoCp}(\text{CO})\text{Cl}$  [4b],  $\text{ClCH}_2\text{FeCl}(\text{CO})_2(\text{PEt}_3)_2$  [3] and  $\text{ClCH}_2\text{IrCp}^*(\text{CO})_2$  [6].

## Experimental

### Preparation

Triethanolamine (0.34 g, 2.3 mmol) and triethylamine (ca. 1 mL, excess) were added to a cooled (0 °C) dichloromethane solution (15 mL) of  $\text{Cl}_3\text{SiMn}(\text{CO})_5$  (0.75 g, 2.27 mmol). The mixture was allowed to warm to room temperature and stirred for 18 h. The solvent evaporated quickly under vacuum, and the residue was extracted with diethylether. The solvent was removed from the filtered extract and the residue sublimed without heating, under a static vacuum, on to a cold finger. Transparent, well-formed crystals were produced and identified by the X-ray structure determination as  $\text{ClCH}_2\text{Mn}(\text{CO})_5$  (**1**) (0.036 g, 7%). Infrared spectrum:  $\nu(\text{CO})$  (hexane,  $\text{cm}^{-1}$ ) 2120w, 2024s, br, 2001s.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  3.58 ( $\text{CH}_2$ ).

### Structure determination

Suitable crystals of **1** were obtained by sealing a small amount of sample in an evacuated glass ampoule (ca 0.5 mL) and allowing crystals to grow by sublimation—body heat was sufficient to cause the crystals to sublime from one end of the ampoule to the other. Crystal data are summarised in Table 1. Data were collected on a Siemens P4 diffractometer and processed using standard software.

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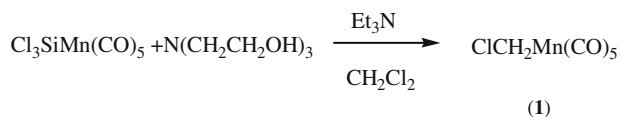
**Table 1** Crystal data and structure refinement details for **1**

Molecular formula	C <sub>6</sub> H <sub>2</sub> ClMnO <sub>5</sub>
Formula weight	244.47
Temperature	158(2) K
Wavelength	0.71073 Å
Crystal system, space group	Monoclinic, <i>P</i> <sub>2</sub> <sub>1</sub> / <i>c</i>
Unit cell dimensions	
<i>a</i> (Å)	11.265(4)
<i>b</i> (Å)	14.167(14)
<i>c</i> (Å)	11.715(3)
β(°)	111.36(1)
Volume (Å <sup>3</sup> )	1741.2(18)
<i>Z</i>	8
Density (calc.) g cm <sup>-3</sup>	1.865
Absorption coefficient (mm <sup>-1</sup> )	1.806
<i>F</i> (000)	960
Crystal size (mm <sup>3</sup> )	0.46 × 0.42 × 0.35
θ range for data collection (°)	2.4–25.0°
Reflections collected	3384
Unique reflections	3018 [ <i>R</i> (int) = 0.0881]
Completeness to θ = 26.31	98.4%
Absorption correction	psi-scan
Max. and min. transmission	0.571 and 0.490
Data/restraints/parameters	3081/0/235
Goodness-of-fit on <i>F</i> <sup>2</sup>	1.038
<i>R</i> indices [ <i>I</i> > 2σ( <i>I</i> )]	<i>R</i> <sub>1</sub> = 0.0640, <i>wR</i> <sub>2</sub> = 0.1458
<i>R</i> indices (all data)	<i>R</i> <sub>1</sub> = 0.1048, <i>wR</i> <sub>2</sub> = 0.1545
Largest diff. features (e Å <sup>-3</sup> )	0.71 and -1.32

The structure was solved with SHELXS-97 and refined (on *F*<sup>2</sup>) using SHELXL-97 [7]. All non-hydrogen atoms were treated anisotropically and CH<sub>2</sub> hydrogen atoms were included with a riding model with d(C–H) 0.99 Å, U<sub>iso</sub> = 1.2U<sub>eq</sub>(C). ORTEP-3 was used for the Figure [8].

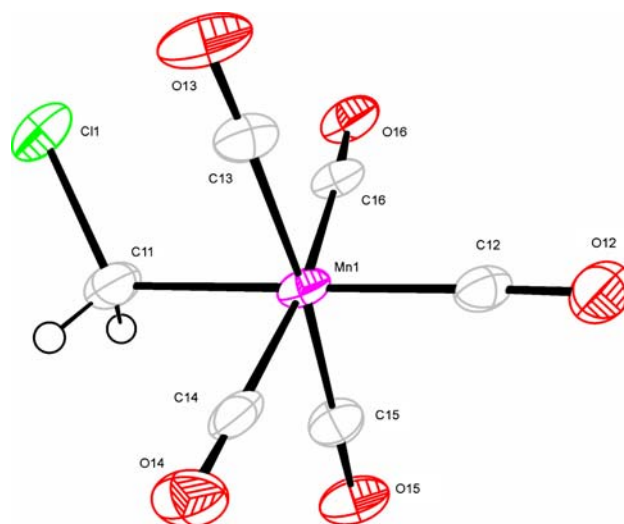
## Results and discussion

In an attempt to prepare a silatrane derivative of Mn(CO)<sub>5</sub>, triethanolamine reacted with Cl<sub>3</sub>SiMn(CO)<sub>5</sub> in CH<sub>2</sub>Cl<sub>2</sub> with excess Et<sub>3</sub>N present. However, the only tractable species isolated was ClCH<sub>2</sub>Mn(CO)<sub>5</sub>, in somewhat low yields (Scheme 1). Presumably, the ClCH<sub>2</sub> ligand is derived from the solvent, by nucleophilic attack of [Mn(CO)<sub>5</sub>]<sup>-</sup> generated in situ from cleavage of the Si–Mn bond by the amine. A more rational synthesis of **1** from ClCH<sub>2</sub>I and pre-formed [Mn(CO)<sub>5</sub>]<sup>-</sup> is available [9]. ClCH<sub>2</sub>Mn(CO)<sub>5</sub> is surprisingly very volatile, so that X-ray data collection at low temperature, 158 K, was required. It forms beautiful diamond-like crystals by vacuum sublimation with very mild warming.

**Scheme 1** Synthesis of **1**

The X-ray crystal structure determination of **1** revealed two crystallographically independent molecules in the asymmetric unit (see below for a detailed analysis of the relationship between the two molecules). The structure is shown in Fig. 1 for one of the molecules (the other does not differ significantly). There is the expected pseudo-octahedral coordination around the Mn atom. The average Mn–C bond to the alkyl group is 2.128(8) Å, longer than the corresponding distance in ClCH<sub>2</sub>Co(CO)<sub>3</sub>(PPh<sub>3</sub>) of 2.022(3) Å [4], as expected for the larger manganese atom; the M–C–Cl angles for the two are 117.0(4) and 116.4(4)°, respectively. Only limited comparisons with simpler RMn(CO)<sub>5</sub> molecules are possible because of paucity of data for examples where *R* is bonded through an sp<sup>3</sup> carbon atom. Attempts to define the parent CH<sub>3</sub>Mn(CO)<sub>5</sub> were thwarted by disorder [10]. However, the Mn–C bond length of 2.128(8) Å is shorter than those in PhOOCCH = CHCH<sub>2</sub>Mn(CO)<sub>5</sub> (2.214 Å [11]) or 1,2-C<sub>6</sub>H<sub>4</sub>[C<sub>2</sub>H<sub>4</sub>Mn(CO)<sub>5</sub>]<sub>2</sub> (2.196 Å [12]), and similar to that in (PhO)<sub>2</sub>CHMn(CO)<sub>5</sub> (2.141 Å [13]), which are also bonded through sp<sup>3</sup> carbon atoms (Table 2).

In ClCH<sub>2</sub>Mn(CO)<sub>5</sub> the average Mn–C<sub>axial</sub> distance (*trans* to ClCH<sub>2</sub> group) of 1.847(9) Å is shorter than the average Mn–C<sub>equatorial</sub> distance of 1.864(9) Å, as expected *trans* to a non-π-accepting alkyl ligand. The average C–Cl distance of 1.811(8) Å is normal for a Cl–C(sp<sup>3</sup>) bond. There is, therefore, no indication of any η<sup>2</sup> contribution towards the bonding, of the type analysed for XCH<sub>2</sub>

**Fig. 1** The structure of molecule **1** of ClCH<sub>2</sub>Mn(CO)<sub>5</sub>, with ellipsoids plotted at the 50% level

**Table 2** Selected bond lengths (Å) and angles (°) for **1**

	Molecule 1	Molecule 2
Mn1–C1	2.125(10)	2.130(10)
Mn1–C2	1.836(10)	1.856(11)
Mn1–C3	1.864(9)	1.855(8)
Mn1–C4	1.883(9)	1.861(9)
Mn1–C5	1.843(9)	1.849(9)
Mn1–C6	1.862(8)	1.893(9)
C1–Cl1	1.806(8)	1.817(8)
Mn1–C1–Cl1	117.0(4)	116.4(4)

substituents by Siegbahn [14], presumably because the manganese atom has already achieved an eighteen-electron configuration.

The equatorial carbonyl groups are bent towards the alkyl group, so that the average C–Mn–C<sub>equatorial</sub> angle is 86.2(4)°. This ‘umbrella’ effect is well established [15].

A careful examination of the two independent molecules in the asymmetric unit revealed an apparent relationship, which raised the possibility of a mis-assigned space group [16], so that a more detailed analysis was carried out. The corresponding atoms from the two molecules showed them to be closely related as  $x, y, z$  and  $1/2 - x, 3/4 - y, -z$ , which is not a crystallographic relationship between coordinates in  $P2_1/c$  but does correspond to an apparent centre of symmetry at  $1/4; 3/8; 0$ . This is a non-crystallographic or local centre of symmetry, but it is not unusual to find such local centres. For example, Marsh et al. have found several structures, having space group  $Pca2_1$  or  $Pna2_1$  with more than one molecule in the asymmetric unit, containing local centres of symmetry [17], and Dalhus and Henrik also report another example, in  $Pca2_1$  [18]. A situation similar to that observed for **1** was reported for 2-methylpyrazine [19] which crystallizes in the tetragonal space group  $I-4$  with two independent molecules in the asymmetric unit. The two molecules are approximately related as  $x, y, z$  and  $1/2 - x, y, -1/4 + z$ , which is not a crystallographic symmetry operation. However, 2-methylpyrazine crystallizes as twinned crystals with a twin law  $R = (010, 100, 00-1)$ , i.e. the two twin domains are related by a two fold axis along [110]. The  $R$  factors using standard refinement methods (i.e. without twin) were  $wR_2 = 0.272$ ,  $R_1 = 0.104$ , but with the introduction of the twin law the  $R$  factors dropped to  $wR_2 = 0.0676$ ,  $R_1 = 0.0271$  [19].

Considering that in the crystals of **1** investigated in the present article,  $a^*$  and  $c^*$  are nearly equal, it is possible that twinning by merohedry may also be present here, in that there could be two domains with two reciprocal lattices exactly coincident. Thus, we tried a twin-refinement with the original cell parameters and space group  $P2_1/c$  using the twin law  $R = (0\ 0\ 1, 0\ -1\ 0, 1\ 0\ 0)$ , covering the

situation where the two domains (if they existed) would be related by a two fold axis along [101]. However, the batch scale factor refined to 0.0048, suggesting that a second twin-domain does not exist. We also attempted a second twin-refinement with the original cell parameters and space group  $P2_1/c$  using the twin law  $R = (0\ 0\ 1, 0\ -1\ 0, 1\ 0\ 0)$ , for the case where the two domains would be related by a two fold axis along  $[-101]$ ; again the batch scale factor refined to 0.0048. Other more complicated twin refinements were examined without success. It is noted that the reflections are very strong when  $h = \text{odd}$  and  $k = 2, 6, 10, 14...$  or when  $h = \text{even}$  and  $k = 4, 8, 12, 16$ , but this behaviour is completely explained by the presence of the two independent molecules related by the non-crystallographic centre at  $1/4; 3/8; 0$ . The situation in (h0l) is more complicated because the reflections with  $h + 1 = 2n + 1$  are weak, which may suggest an  $n$ -glide; however, there are 10 h0l reflections (but not strong) with  $h + 1 = 2n + 1$  and with  $I > 3\sigma(I)$ , so that this unusual systematic extinction in  $P2_1/c$  is not significant. We therefore conclude that the refinement reported here is correct in  $P2_1/c$ , with  $Z' = 2$ .

### Supplementary material

CCDC 673810 contains the supplementary crystallographic data for this article. These data can be obtained free of charge at <http://www.ccdc.cam.ac.uk/conts/retrieving.html>, or from the Cambridge Crystallographic Data Centre, 12 Union Rd, Cambridge CB2 1EZ, UK; email: [deposit@ccdc.cam.ac.nz](mailto:deposit@ccdc.cam.ac.nz).

### References

- Friedrich HB, Moss JR (1991) Adv Organometal Chem 33:235
- Ogino H, Shoji M, Abe Y, Shimura M, Shimoi M (1987) Inorg Chem 26:2542; Abe Y, Ogino H (1989) Bull Chem Soc Jpn 62:56
- Kandler H, Bidell W, Janicke M, Knickmeier M, Veghini D, Berke H (1998) Organometallics 17:960
- (a) Galamb V, Palyi G, Boese R, Schmid G (1987) Organometallics 6:861; (b) Olson WL, Nagaki DA, Dahl LF (1986) Organometallics 5:630; (c) Geremia S, Calligaris M, Randaccio L (1999) Eur J Inorg Chem 6:981; (d) Lee S, Espenson JH, Bakac A (1990) Inorg Chem 29:3442; (e) Lopez C, Alvarez S, Solans X, Font-Bardia M (1992) Polyhedron 11:1637; (f) Polson SM, Cini R, Pifferi C, Marzilli LG (1997) Inorg Chem 36:314; (g) Dreos R, Nardin G, Randaccio L, Siega P, Tauzher G, Vrdoljak V (2003) Inorg Chem 42:6805
- Charette AB, Marcoux JF, Molinaro C, Beauchemin A, Brochu C, Isabel E (2000) J Am Chem Soc 122:4508; Charette AB, Molinaro C, Brochu C (2001) J Am Chem Soc 123:12160
- Einstein FWB, Glavina PG, Pomeroy RK, Rushman P, Willis AC (1986) J Organometal Chem 317:255
- Sheldrick GM (1997) SHELX-97. Programs for the solution and refinement of crystal structures. Universität Göttingen, Germany

8. Farrugia LJ (1997) *J Appl Cryst* 30:565
9. Moss JR, Pelling S (1982) *J Organometal Chem* 236:221
10. Andrews MA, Eckert J, Goldstone JA, Passell L, Swanson B (1983) *J Am Chem Soc* 105:2262
11. Masters AP, Richardson JF, Sorensen TS (1990) *Can J Chem* 68:2221
12. Lindner E, Wassing W, Fawzi R, Steimann M (1993) *Z Naturforsch B* 48:1651
13. Lowe C, Huttner G, Zsolnai L, Berke H (1988) *Z Naturforsch B* 43:25
14. Siegbahn PEM (1994) *J Am Chem Soc* 116:7722
15. Jackson SA, Eisenstein O, Martin JD, Albeniz AC, Crabtree RH (1991) *Organometallics* 10:3062
16. Marsh RE, Clemente DA (2007) *Inorg Chim Acta* 360:4017, and references therein
17. Marsh RE, Schomaker V, Herbststein FH (1998) *Acta Cryst B* 54:921
18. Dalhus B, Henrik C (2000) *Acta Cryst B* 56:715
19. Boese R, Gehrke A, Kapon M, Herbststein FH (2000) *Acta Cryst B* 56:677