



University of North Florida  
**UNF Digital Commons**

Chemistry Faculty Publications

Department of Chemistry

6-2005

# 1,12-Diferrocenyldodecane at 100 K

Danielle M. Bequeath

Richard L. Porter

Michael W. Lufaso

*University of North Florida*, [michael.lufaso@unf.edu](mailto:michael.lufaso@unf.edu)

Timothy R. Wagner

Rachel L. Kusnic

*See next page for additional authors*

Follow this and additional works at: [http://digitalcommons.unf.edu/achm\\_facpub](http://digitalcommons.unf.edu/achm_facpub)

 Part of the [Chemistry Commons](#)

## Recommended Citation

Bequeath, Danielle M.; Porter, Richard L.; Lufaso, Michael W.; Wagner, Timothy R.; Kusnic, Rachel L.; Zeller, Matthias; and Curtin, Larry S., "1,12-Diferrocenyldodecane at 100 K" (2005). *Chemistry Faculty Publications*. 5.  
[http://digitalcommons.unf.edu/achm\\_facpub/5](http://digitalcommons.unf.edu/achm_facpub/5)

This Article is brought to you for free and open access by the Department of Chemistry at UNF Digital Commons. It has been accepted for inclusion in Chemistry Faculty Publications by an authorized administrator of UNF Digital Commons. For more information, please contact [Digital Projects](#).  
© 6-2005 All Rights Reserved



---

**Authors**

Danielle M. Bequeath, Richard L. Porter, Michael W. Lufaso, Timothy R. Wagner, Rachel L. Kusnic, Matthias Zeller, and Larry S. Curtin

## 1,12-Diferrocenyldodecane at 100 K

Danielle M. Bequeath, Richard L. Porter, Michael W. Lufaso, Timothy R. Wagner, Rachel L. Kusnic, Matthias Zeller and Larry S. Curtin\*

Department of Chemistry, Youngstown State University, 1 University Plaza, Youngstown, OH 44555-3663, USA

Correspondence e-mail: lscurtin@cc.yosu.edu

### Key indicators

Single-crystal X-ray study  
T = 100 K  
Mean  $\sigma(\text{C}-\text{C}) = 0.002 \text{ \AA}$   
R factor = 0.026  
wR factor = 0.075  
Data-to-parameter ratio = 25.9

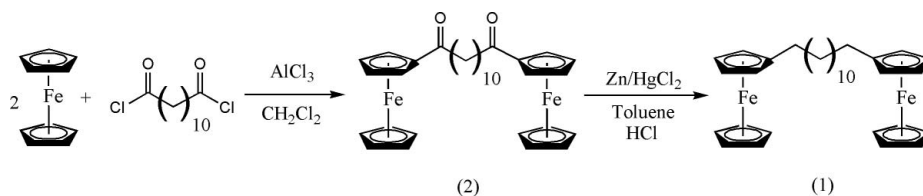
For details of how these key indicators were automatically derived from the article, see <http://journals.iucr.org/e>.

1,12-Diferrocenyldodecane,  $[\text{Fe}_2(\text{C}_5\text{H}_5)_2(\text{C}_{22}\text{H}_{32})]$ , was synthesized from ferrocene and 1,12-dodecanedioyl chloride, followed by Clemmensen reduction. The single-crystal structure was determined at 100 K by X-ray diffraction and the spectroscopic and cyclic voltammetric data of 1,12-diferrocenyldodecane and its precursor are reported.

Received 11 April 2005  
Accepted 28 April 2005  
Online 14 May 2005

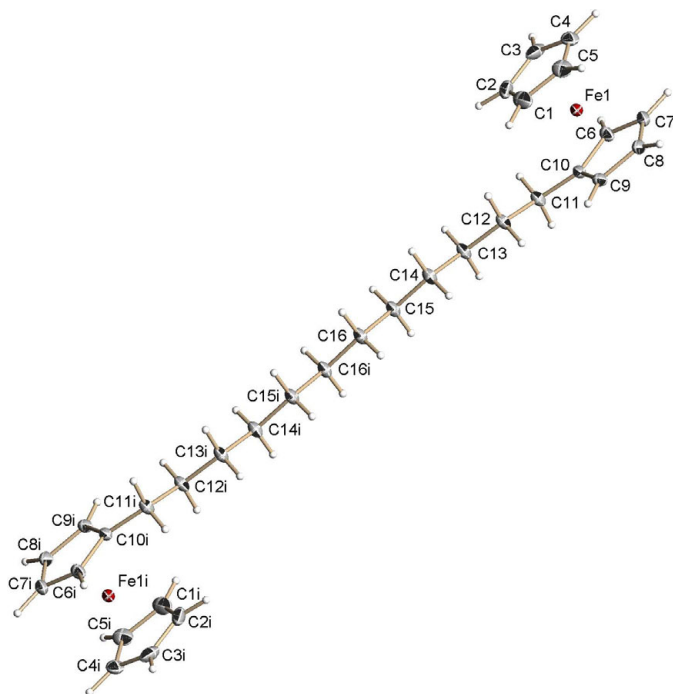
### Comment

Ferrocene-containing compounds have been extensively studied due to their unique structural and electrochemical properties. Ferrocenes have also been investigated with regard to their potential applications in chemical sensing, redox catalysts, ferromagnetism and self-assembled monolayers (Togni & Hayashi, 1995; Sawamura & Ito, 1992; Nicolosi *et al.*, 1994; Sammakia *et al.*, 1995; Beer *et al.*, 1993; Zhang *et al.*, 1995; Chidsey *et al.*, 1990; Creager & Rowe, 1997). As an intermediate in the synthesis of self-assembled monolayers with multiple redox centers, 1,12-diferrocenyldodecane, (1), was synthesized *via* Clemmensen reduction of its precursor 1,12-diferrocenyldodecane-1,12-dione, (2), and its solid-state structure was established by X-ray diffraction at 100 K.



1,12-Diferrocenyldodecane crystallizes in the monoclinic space group  $P2_1/c$  with two molecules in the unit cell (Fig. 1). The center of each molecule is located on a crystallographic inversion center halfway between C16 and C16<sup>i</sup> [symmetry code: (i)  $-x + 1, -y + 1, -z + 2$ ]. The dodecane chain forms an extended zigzag chain. All torsion angles in the chain are close to  $180^\circ$  [between  $175.70(6)^\circ$  for  $\text{C}12 \cdots \text{C}14 \cdots \text{C}16$  and  $179.39(6)^\circ$  for  $\text{C}14 \cdots \text{C}16 \cdots \text{C}15^i$ ].

The C—C single bonds of the dodecane chain close to the ferrocene unit alternate slightly; the C10—C11 bond length between the ferrocene unit and the first methylene C atom is  $1.501(1) \text{ \AA}$  and that of C11—C12 is  $1.529(1) \text{ \AA}$ . All other C—C bond distances within the dodecane chain are identical within experimental error:  $1.525(1)$ ,  $1.525(1)$ ,  $1.526(1)$ ,  $1.523(1)$  and  $1.525(2) \text{ \AA}$  for C12—C13, C13—C14, C14—C15, C15—C16, and C16—C16<sup>i</sup>, respectively. The bond distances within the ferrocene units are unexceptional, with the unsubstituted ring having basically identical C—C bond distances of  $1.424(2) \text{ \AA}$ , and C—C distances of the substituted



**Figure 1**  
The molecular structure of (1), showing 50% probability displacement ellipsoids. [symmetry code: (i)  $-x + 1, -y + 1, -z + 2$ ]

ring being between 1.429 (2) and 1.433 (2) Å.

The  $\text{Fe1} \cdots \text{Fe1}^{\text{i}}$  distance within one molecule is 18.7196 (9) Å in the solid state. The closest  $\text{Fe} \cdots \text{Fe}$  distances between different molecules are 6.3972 (3) Å for  $\text{Fe1} \cdots \text{Fe1}^{\text{ii}}$  [symmetry code: (ii)  $x, \frac{1}{2} - y, z + \frac{1}{2}$ ] and 7.1275 (3) Å for  $\text{Fe1} \cdots \text{Fe1}^{\text{iii}}$  [symmetry code: (iii)  $x, \frac{3}{2} - y, z + \frac{1}{2}$ ].

## Experimental

1,12-Diferrocenyldodecane-1,12-dione, (2), was synthesized from ferrocene and 1,12-dodecanedioyl chloride *via* the method of Chidsey *et al.* (1990) and was reduced to the title compound, (1), by Clemmensen reduction, as described by Creager & Rowe (1997). Ferrocene (35.00 g, 0.188 mmol) was dissolved at 273 K in  $\text{CH}_2\text{Cl}_2$  (250 ml). 1,12-Dodecanedioyl chloride (25.00 g, 0.0935 mmol) was added and the resulting solution was stirred for 5 min. Anhydrous  $\text{AlCl}_3$  (27.50 g, 0.207 mmol) was added and the solution was allowed to warm to room temperature and stirred for 1.5 h. De-ionized water (300 ml) was added dropwise and the mixture was stirred for an additional 1.5 h. The organic phase was washed with five portions of de-ionized water, then three times with brine, and dried over anhydrous sodium sulfate. The solvent was removed *in vacuo*. The crude product was purified *via* column chromatography on silica with 80/20% hexanes/ethyl acetate as the eluent. The second band to elute ( $R_F = 0.75$ ) contained the desired product, (2), in 12.2% yield.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  1.322 [*m*, 12H,  $(\text{CH}_2)_6$ ], 1.701 (*m*, 4H,  $\text{COCH}_2\text{CH}_2$ ), 2.692 (*t*, 4H,  $\text{COCH}_2$ ), 4.194 (*s*, 10H,  $\text{C}_5\text{H}_5$ ), 4.487 (*t*, 4H,  $\text{C}_5\text{H}_4$ ), 4.780 (*t*, 4H,  $\text{C}_5\text{H}_4$ ). MS: calculated for  $(1^+)$  566 *m/z*, found 566 *m/z*. CV [1.6 mm diameter Pt disc working, Pt wire counter, non-aqueous  $\text{Ag}/\text{Ag}^+$  reference electrodes, 1.0 mM (2), 0.1 M  $\{(n-\text{C}_4\text{H}_9)\text{N}\}\text{ClO}_4$  in  $\text{CH}_3\text{CN}$ ]: reversible single, two-electron oxidation

centered at  $E^\circ = +266$  mV. 1,12-Diferrocenyldodecane-1,12-dione, (2) (9.02 g, 0.0158 mol), dissolved in toluene (800 ml), was mixed with freshly prepared zinc/mercury amalgam [mercuric chloride (1.06 g, 0.039 mol), zinc dust (15.79 g, 0.024 mol), de-ionized water (30 ml) and 12.1 M HCl (40 ml)] and was refluxed under static argon for 20 h. Two additional 30 ml portions of 12.1 M HCl were added with an addition funnel after 6 and 12 h under reflux. Upon cooling, the organic phase was washed three times with de-ionized water and three times with brine, and was dried over anhydrous sodium sulfate. The solvent was removed *in vacuo*. The crude product was purified *via* column chromatography on silica with 75/25% hexanes/ethyl acetate as the eluent. The first band to elute ( $R_F = 0.9$ ) contained the desired product, *viz.* 1,12-diferrocenyldodecane, (1).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  1.199 [*m*, 16H,  $(\text{CH}_2)_8$ ], 1.417 (*m*, 4H,  $\text{CpCH}_2\text{CH}_2$ ), 2.228 (*t*, 4H,  $\text{CpCH}_2$ ), 3.976 (*s*, 4H,  $\text{C}_5\text{H}_4$ ), 3.996 (*s*, 4H,  $\text{C}_5\text{H}_4$ ), 4.032 (*s*, 10H,  $\text{C}_5\text{H}_5$ ). MS: calculated for  $(2^+)$  538 *m/z*, found 538 *m/z*. CV [1.6 mm diameter Pt disc working, Pt wire counter, non-aqueous  $\text{Ag}/\text{Ag}^+$  reference electrodes, 1.0 mM (1), 0.1 M  $\{(n-\text{C}_4\text{H}_9)\text{N}\}\text{ClO}_4$  in  $\text{CH}_3\text{CN}$ ]: reversible single, two-electron oxidation centered at  $E^\circ = -25$  mV. Single crystals of (1) were grown from a 75/25% hexanes/ethyl acetate solution by slow evaporation.

## Crystal data

$[\text{Fe}_2(\text{C}_5\text{H}_5)_2(\text{C}_{22}\text{H}_{32})]$   
 $M_r = 538.36$   
Monoclinic,  $P2_1/c$   
 $a = 16.0203$  (9) Å  
 $b = 7.5367$  (4) Å  
 $c = 11.1773$  (6) Å  
 $\beta = 103.597$  (1)°  
 $V = 1311.73$  (12) Å<sup>3</sup>  
 $Z = 2$

$D_x = 1.363$  Mg m<sup>-3</sup>  
Mo  $K\alpha$  radiation  
Cell parameters from 6072 reflections  
 $\theta = 2.7\text{--}30.5^\circ$   
 $\mu = 1.12$  mm<sup>-1</sup>  
 $T = 100$  (2) K  
Block, red  
 $0.47 \times 0.29 \times 0.25$  mm

## Data collection

Bruker SMART APEX CCD diffractometer  
 $\omega$  scans  
Absorption correction: multi-scan (*SADABS* in *SAINT-Plus*; Bruker, 2003)  
 $T_{\text{min}} = 0.644$ ,  $T_{\text{max}} = 0.75$   
15 135 measured reflections

3988 independent reflections  
3769 reflections with  $I > 2\sigma(I)$   
 $R_{\text{int}} = 0.018$   
 $\theta_{\text{max}} = 30.5^\circ$   
 $h = -22 \rightarrow 22$   
 $k = -10 \rightarrow 10$   
 $l = -15 \rightarrow 15$

## Refinement

Refinement on  $F^2$   
 $R[F^2 > 2\sigma(F^2)] = 0.026$   
 $wR(F^2) = 0.075$   
 $S = 1.07$   
3988 reflections  
154 parameters  
H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + (0.0461P)^2 + 0.3363P]$   
where  $P = (F_o^2 + 2F_c^2)/3$   
 $(\Delta\sigma)_{\text{max}} = 0.001$   
 $\Delta\rho_{\text{max}} = 0.45$  e Å<sup>-3</sup>  
 $\Delta\rho_{\text{min}} = -0.37$  e Å<sup>-3</sup>

All H atoms were placed in calculated positions, with a C—H bond distance of 0.99 (methylene) or 1.00 Å (Cp), and were refined with isotropic displacement parameters 1.2 times  $U_{\text{eq}}$  of the parent C atom. The s.u. values of the cell parameters are taken from the software, recognizing that the values are unreasonably small (Herbst, 2000).

Data collection: *SMART* (Bruker, 2002); cell refinement: *SAINT-Plus* (Bruker, 2003); data reduction: *SAINT-Plus*; program(s) used to solve structure: *SHELXTL* (Bruker, 2000); program(s) used to refine structure: *SHELXTL*; molecular graphics: *SHELXTL*; software used to prepare material for publication: *SHELXTL*.

LSC was supported by a YSU Research Professorship (1996–1997) and by Youngstown State University Research Council Grants (Nos. 961, 10-2001 and 06-98), and the diffractometer was funded by NSF grant No. 0087210, by Ohio Board of Regents grant CAP-491, and by YSU.

### References

- Beer, P. D., Crowe, D. B., Ogden, M. I., Drew, M. G. B. & Main, B. (1993). *J. Chem. Soc. Dalton Trans.* pp. 2107–2116.
- Bruker (2000). *SHELXTL*. Version 6.10. Bruker AXS Inc., Madison, Wisconsin, USA.
- Bruker (2002). *SMART for WNT/2000*. Version 5.630. Bruker AXS Inc., Madison, Wisconsin, USA.
- Bruker (2003). *SAINT-Plus*. Version 6.45. Bruker AXS Inc., Madison Wisconsin, USA.
- Chidsey, C. E. D., Bertozzi, C. R., Putvinski, T. M. & Majsce, A. M. (1990). *J. Am. Chem. Soc.* **112**, 4301–4306.
- Creager, S. E. & Rowe, G. K. (1997). *J. Electroanal. Chem.* **420**, 291–299.
- Herbstein, F. H. (2000). *Acta Cryst.* **B56**, 547–557.
- Nicolosi, G., Patti, R., Morrone, R. & Piatelli, M. (1994). *Tetrahedron Asymmetry*, **5**, 1639–1642.
- Sammakia, T., Latham, H. A. & Schaad, D. R. (1995). *J. Org. Chem.* **60**, 10–11.
- Sawamura, M. & Ito, Y. (1992). *Chem. Rev.* **92**, 857–871.
- Togni, A. & Hayashi, T. (1995). Editors. *Ferrocenes: Homogeneous Catalysis, Organic Synthesis, Materials Science*. Weinheim, Germany: Verlag Chemie.
- Zhang, L., Godinez, L. A., Lu, T., Gokel, G. W. & Kaifer, A. E. (1995). *Angew. Chem. Int. Ed. Engl.* **34**, 235–237.