

Short Communication

Synthesis and Crystal Structure of (*E*)-[7-(Ferrocenylmethylene)-4,5,6,7-tetrahydro- 1-methyl-1*H*-indazol-3-yl]ferrocene, C₂₉H₂₈Fe₂N₂

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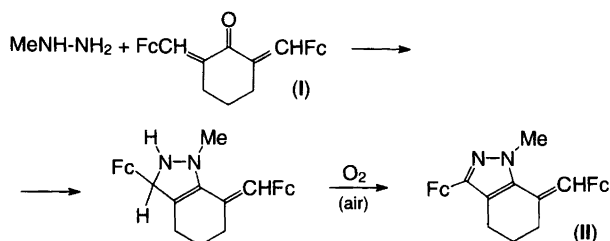
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Cross-conjugated dienones of type **I** (Scheme 1) with different aryl substituents instead of Fc have been shown to have cytotoxic activity vs. certain leukemias.¹ We were interested in possible biological effects of nitrogen derivatives, so we condensed methylhydrazine with **I** to prepare such a derivative (**II**). A logical approach to the reaction mechanism would be via initial conjugate attack of methylhydrazine on **I**.² The X-ray study was undertaken to determine the exact structure of **II**.

Experimental

Synthesis. Methylhydrazine (2.00 g, 43.41 mmol) and **I** (0.50 g, 1.02 mmol) were dissolved in 50 ml of methanol. The mixture was stirred under reflux for 24 h, then cooled for 48 h. Spiky orange–brown crystals were collected by filtration and washed with cold methanol. Recrystallization from methanol yielded 0.43 g (83%) of dark orange crystals of **II**, m.p. 224–225 °C. TLC showed only one spot, *R_f* = 0.57.



Scheme 1.

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Elementary analysis; found: C 65.88, H 5.43, N 5.25. Calcd. for C₂₉H₂₈Fe₂N₂: C 67.47, H 5.47, N 5.43.

¹H NMR (CDCl₃) 1.94 (m, 2H), 2.74 (m, 2H), 2.80 (t, 2H), 4.08 (s, 5H), 4.10 (s, 5H), 4.17 (s, 3H), 4.28 (t, 2H), 4.32 (t, 2H), 4.42 (t, 2H), 4.71 (t, 2H), 6.51 (s, 1H).

¹³C NMR (CDCl₃) 22.2, 24.4, 28.5, 40.0, 66.7, 68.5, 69.1, 69.4, 69.8, 82.2, 115.1, 124.0, 127.0, 139.5, 145.0.

IR (KBr) 1740.01 (m, C=N stretch), 1406 (w, C–C stretch), 1105.35 (m, ferrocene), 1003.11 (w, ferrocene) cm⁻¹.

UV λ_{max} (CCl₄) 306.5 nm, ε = 24 771.5.

Structure determination. Cell dimensions (Table 1) were obtained from setting angles of 25 carefully centered reflections, using a least-squares procedure. Intensities and positions of three standard reflections have been checked every 2 h during the data collection. No crystal decay (within 3%) was observed. The raw data were processed the usual way and corrected for Lorentz and polarization effects (not for absorption owing to a negligible μ_R value, ca. 0.1). The structure was solved using direct methods³ and refined by a full-matrix least squares program⁴ using anisotropic temperature factors for all non-hydrogen atoms. All hydrogens were put into refinement isotropically in calculated positions (riding model, orientation of methyl hydrogens was optimized). The isotropic thermal parameters were required to have the same value for every group of hydrogens connected to the same carbon atom or to the same Cp ring.

Crystallographic and structure refinement data are listed in Table 1. Coordinates and equivalent isotropic thermal parameters of non-hydrogen atoms are listed in Table 2. The molecular structure is shown in Fig. 1.

Table 1. Crystal and structure refinement data for II.

Empirical formula	C ₂₉ H ₂₈ Fe ₂ N ₂
Temperature/K	103(2)
Diffractometer	Enraf-Nonius CAD4
Wavelength/Å	0.710 69
Crystal system	Triclinic
Space group	<i>P</i> $\bar{1}$
<i>a</i> /Å	9.788(3)
<i>b</i> /Å	10.185(6)
<i>c</i> /Å	11.213(3)
α /°	83.82(4)
β /°	81.25(2)
γ /°	85.72(4)
<i>V</i> /Å ³	1096.5(8)
Formula weight	516.23
<i>Z</i>	2
<i>D</i> _{calc} /g cm ⁻³	1.564
μ (MoK α)/mm ⁻¹	1.344
Crystal size/mm ³	0.12 × 0.15 × 0.22
θ range ($\omega/2\theta$ -scan)/°	2.6–26.0
Independent reflections collected	4289
Independent reflections observed [<i>I</i> > 2 σ (<i>I</i>)]	2872
Refinement method	Full-matrix least-squares on all <i>F</i> ²
Data/restraints/parameters	4238/0/308
Goodness-of-fit on <i>F</i> ²	0.943
Final <i>R</i> -indices [<i>I</i> > 2 σ (<i>I</i>)]	<i>R</i> ₁ = 0.0637, <i>wR</i> ₂ = 0.1554
<i>R</i> -indices (all data)	<i>R</i> ₁ = 0.1153, <i>wR</i> ₂ = 0.1826
Largest difference peak and hole/e Å ⁻³	1.732 and –1.857

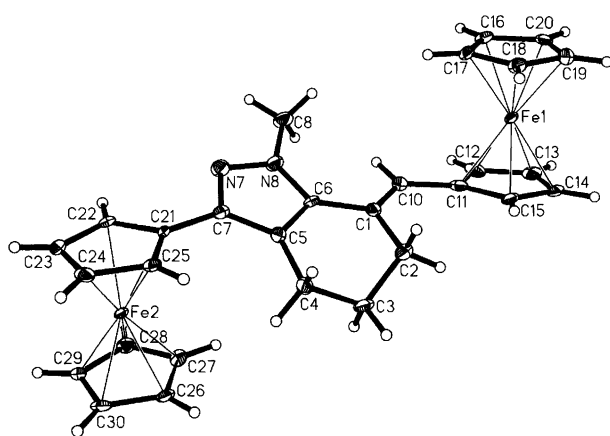


Fig. 1. Perspective view of the molecule II showing the labelling of non-hydrogen atoms and 50% probability displacement ellipsoids. Distances Fe...C are shown by single lines.

Further details of the structural work are deposited with the Cambridge Crystallographic Data Centre, UK.

Results and discussion

It has been shown that the compound II is a tetrahydroindazole derivative: (*E*)-[7-(ferrocenylmethylene)-4,5,6,7-tetrahydro-1-methyl-1*H*-indazol-3-yl]ferrocene. The prac-

Table 2. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters (in Å² $\times 10^3$) for non-hydrogen atoms.

Atom	<i>x</i>	<i>y</i>	<i>z</i>	<i>U</i> _{eq} ^a
Fe(1)	–3187(1)	1866(1)	181(1)	11(1)
Fe(2)	3421(1)	3060(1)	6371(1)	11(1)
C(1)	–207(4)	2443(5)	2294(4)	16(1)
C(2)	550(5)	3533(5)	1488(4)	21(1)
C(3)	1942(5)	3758(5)	1879(4)	20(1)
C(4)	1772(5)	4155(5)	3163(4)	16(1)
C(5)	849(5)	3238(5)	3991(4)	15(1)
C(6)	–55(4)	2453(4)	3569(4)	14(1)
C(7)	665(5)	2950(5)	5258(4)	15(1)
N(7)	–297(4)	2071(4)	5617(3)	18(1)
N(8)	–719(4)	1766(4)	4571(3)	19(1)
C(8)	–1812(5)	842(5)	4730(4)	21(1)
C(10)	–958(5)	1565(5)	1894(4)	16(1)
C(11)	–1255(4)	1492(5)	667(4)	15(1)
C(12)	–1752(5)	307(5)	293(4)	20(1)
C(13)	–2010(5)	579(5)	–913(4)	21(1)
C(14)	–1690(5)	1884(6)	–1316(4)	22(1)
C(15)	–1233(5)	2479(5)	–345(4)	19(1)
C(16)	–4975(5)	1419(5)	1323(4)	16(1)
C(17)	–4389(5)	2535(4)	1672(4)	13(1)
C(18)	–4298(5)	3532(5)	699(4)	17(1)
C(19)	–4844(5)	3038(5)	–276(4)	19(1)
C(20)	–5261(4)	1738(5)	108(4)	15(1)
C(21)	1369(4)	3435(5)	6168(4)	13(1)
C(22)	1500(4)	2728(5)	7318(4)	15(1)
C(23)	2244(5)	3508(5)	7963(4)	20(1)
C(24)	2571(5)	4678(5)	7207(4)	18(1)
C(25)	2042(4)	4654(4)	6101(4)	14(1)
C(26)	4995(4)	3183(5)	4946(4)	15(1)
C(27)	4292(5)	2001(4)	4975(4)	15(1)
C(28)	4393(5)	1245(5)	6101(4)	17(1)
C(29)	5163(4)	1976(5)	6771(4)	16(1)
C(30)	5532(4)	3146(5)	6065(4)	16(1)

^a *U*_{eq} is defined as one third of the trace of the orthogonalized *U*_{ij} tensor.

tically planar [within 0.005(3) Å] five-membered 1,2-imidazole heterocycle is aromatic: the formally 'double' bond C(7)=N(7) of 1.336(6) Å (Table 3) is only slightly shorter than the formally 'single' bond C(6)–N(8) of 1.361(6) Å. Likewise, the 'double' C(5)=C(6) and 'single' C(5)–C(7) bonds are, in practice, equal [1.399(6) and 1.407(6) Å, respectively]. However, this is not quite common for the tetrahydroindazole derivatives. Very often, the endocyclic bonds C=N and C=C have a more pronounced double-bond character. For instance, in analogous dimethyl-1-(*p*-chlorophenyl)-3,4-propano-4,5,6,7-tetrahydroindazole-5,5-dicarboxylate,⁵ where the aromatic system is more or less isolated from π -conjugated groups, the difference is remarkable: 1.312 vs. 1.350 Å for C=N and C–N and 1.355 vs. 1.392 Å for C=C and C–C.

Evidently, this additional delocalization of the heterocyclic π -system occurs under the influence of a long chain of π -conjugation in the compound investigated: dihedral angles in the sequence Cp/imidazole/[C(1)=C(10)]/Cp are 24.5(3), 9.3(8) and 19.0(5)°, respectively. The formally single C(sp²)–C(sp²) bonds C(21)–C(7),

Table 3. Bond lengths (in Å) and selected bond angles (in °).

Fe(1)–C(11)	2.044(4)	C(5)–C(7)	1.407(6)
Fe(1)–C(12)	2.047(5)	C(6)–N(8)	1.361(6)
Fe(1)–C(13)	2.059(5)	C(7)–N(7)	1.336(6)
Fe(1)–C(14)	2.053(5)	C(7)–C(21)	1.460(6)
Fe(1)–C(15)	2.037(4)	N(7)–N(8)	1.373(5)
Fe(1)–C(16)	2.055(4)	N(8)–C(8)	1.456(6)
Fe(1)–C(17)	2.042(4)	C(10)–C(11)	1.460(6)
Fe(1)–C(18)	2.036(5)	C(11)–C(12)	1.459(6)
Fe(1)–C(19)	2.037(5)	C(11)–C(15)	1.431(7)
Fe(1)–C(20)	2.058(4)	C(12)–C(13)	1.408(7)
Fe(2)–C(21)	2.058(4)	C(13)–C(14)	1.400(8)
Fe(2)–C(22)	2.046(4)	C(14)–C(15)	1.443(7)
Fe(2)–C(23)	2.048(4)	C(16)–C(17)	1.427(6)
Fe(2)–C(24)	2.044(5)	C(16)–C(20)	1.430(6)
Fe(2)–C(25)	2.059(5)	C(17)–C(18)	1.406(7)
Fe(2)–C(26)	2.044(4)	C(18)–C(19)	1.439(6)
Fe(2)–C(27)	2.040(4)	C(19)–C(20)	1.418(7)
Fe(2)–C(28)	2.046(5)	C(21)–C(22)	1.427(6)
Fe(2)–C(29)	2.043(5)	C(21)–C(25)	1.437(6)
Fe(2)–C(30)	2.050(4)	C(22)–C(23)	1.434(6)
C(1)–C(2)	1.517(7)	C(23)–C(24)	1.414(7)
C(1)–C(6)	1.461(6)	C(24)–C(25)	1.418(6)
C(1)–C(10)	1.351(7)	C(26)–C(27)	1.426(6)
C(2)–C(3)	1.533(6)	C(26)–C(30)	1.427(7)
C(3)–C(4)	1.519(6)	C(27)–C(28)	1.420(7)
C(4)–C(5)	1.495(6)	C(28)–C(29)	1.436(6)
C(5)–C(6)	1.399(6)	C(29)–C(30)	1.397(7)
C(2)–C(1)–C(6)	112.5(4)		
C(2)–C(1)–C(10)	124.4(4)		
C(6)–C(1)–C(10)	123.1(4)		
C(1)–C(2)–C(3)	112.4(4)		
C(2)–C(3)–C(4)	112.1(4)		
C(3)–C(4)–C(5)	109.8(4)		
C(4)–C(5)–C(6)	122.7(4)		
C(4)–C(5)–C(7)	131.6(4)		
C(6)–C(5)–C(7)	105.7(4)		
C(1)–C(6)–C(5)	124.3(4)		
C(1)–C(6)–N(8)	129.8(4)		
C(5)–C(6)–N(8)	105.9(4)		
C(5)–C(7)–N(7)	111.0(4)		
C(5)–C(7)–C(21)	130.1(4)		
N(7)–C(7)–C(21)	118.9(4)		
C(7)–N(7)–N(8)	105.4(4)		
C(6)–N(8)–N(7)	112.0(4)		
C(6)–N(8)–C(8)	132.1(4)		
N(4)–N(8)–C(8)	115.8(4)		
C(1)–C(10)–C(11)	128.6(4)		
C(10)–C(11)–C(12)	122.3(4)		
C(10)–C(11)–C(15)	130.8(4)		
C(12)–C(11)–C(15)	106.8(4)		
C(7)–C(21)–C(22)	123.8(4)		
C(7)–C(21)–C(25)	128.5(4)		
C(22)–C(21)–C(25)	107.7(4)		

C(6)–C(1) and C(10)–C(11) in this conjugated chain are practically identical [1.460(6), 1.461(6) and 1.460(6) Å] and compare well with the tabular value for conjugated dienes [1.455(11) Å].⁶

The partially saturated six-membered ring has an expected conformation, intermediate between sofa and half-chair (as has most cyclohexene derivatives): atoms C(1), C(4), C(5) and C(6) are coplanar within

0.001(2) Å [the dihedral angle between their mean plane and the plane of the imidazole ring is only 0.6(1)°], and atoms C(2) and C(3) are shifted out of this plane in opposite directions by 0.229(9) and –0.482(9) Å, respectively.

The compound was obtained as the *E*-isomer, as this is probably the least sterically hindered one. The two ferrocenyl groups have an *anti*-orientation relative to the central tetrahydroindazole nucleus. We can not expect any large energetic difference and barrier between *syn* and *anti* conformers of the compound; both of them may be present in solution. So, the occurrence of just the *anti* conformer in the crystal seems to be a result of packing forces.

Both ferrocenyl groups have an undistorted, ordered eclipsed conformation [average torsion angle C–centroid–centroid'–C' is –2.1° at Fe(1) and 2.4° at Fe(2)]. The Cp rings in each of the ferrocenyl groups are nearly parallel [dihedral angle is 4.5(3)° for those at Fe(1) and 1.3(3)° – at Fe(2)]. The C–C bond lengths are 1.397–1.459(7) Å, av. 1.425 Å; the Fe–C bond lengths are 2.036–2.059(5) Å, av. 2.047 Å. The Fe to center of Cp ring distances are 1.648–1.654(2) Å, av. 1.650 Å. These bond distances differ substantially from reported statistical values of 1.397(28), 2.080(35) and 1.706(39) Å, respectively.⁷ The observed increase of the C–C distances in Cp cycles may be a result rather of poor statistical data (systematical underestimation of bond lengths due to a large thermal motion or disorder of the Cp cycles in many structures used for the statistics; the upper quartile value⁷ of 1.415 Å is in better agreement with our data). The shortening of the Fe–Cp distances observed is more difficult to explain, but it may be caused by the abovementioned strong π -conjugation in the molecule, and is not very unusual: our data correspond well to the lower quartile⁷ of the statistical data for Fe–C(Cp) (2.052 Å) and Fe–centroid(Cp) (1.662 Å).

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