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Synthesis, IR-, NMR- and X-ray investigations on some novel *N*-hetaryl-dihydro-pyrazolyl ferrocenes. Study on ferrocenes, part 16 ☆

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Dedicated to Prof. A. Messmer on the occasion of his 80th anniversary

Abstract

Cyclocondensation of 1-aryl-3-ferrocenyl-2-propen-1-ones (**1**) with hetaryl hydrazines resulted in *N*-hetaryl-3-aryl-5-ferrocenyl pyrazolines (**3**, **4**). The analogous 3-aryl-1-ferrocenyl-2-propen-1-ones (**5**) gave the isomeric *N*-hetaryl-5-aryl-3-ferrocenyl-pyrazolines (**6**, **10**), but in lower yield. The reaction of aryl-chalcones (**7**) with 4-hydrazino-phthalazinone led to 3,5-bis-aryl-*N*-hetaryl-pyrazolines (**8**) or to the corresponding ene-hydrazones (**9**). The structure of the new compounds was established by IR, ^{1}H and ^{13}C NMR spectroscopy, including DNOE, HMQC, HMBC and DEPT methods. For compounds **1b**, **3b** and **8b** the stereo structure was elucidated also by X-ray diffraction.

Keywords: Ferrocenes; Enones; Pyrazolines; Hydrazones; Structure by IR; NMR and X-ray

1. Introduction

Ferrocene derivatives containing one or more heterocyclic substituents are useful precursors for the synthesis of new metallocene derivatives [2–8]. At the same time, they are also important because of their potential biological activity [4–6]. Recent publications support that combination of pharmacologically active *N*-heterocycles – among them pyrazolines and pyrazoles – with ferrocene moiety can result in favourable change of biological properties, often associated with decreased toxicity [6–8]. The unique bonding structure and molecular dynamic of ferrocene reflected in the spectral properties make the spectroscopic study of this type of compounds an attractive task.

In the frame of our research program, previously we described the preparation and structure investigation of several new ferrocenyl-triazole, -pyrazole, -pyrazoline and -pyrazolidine derivatives [9,10] via 1,3-dipolar cycloaddition of ferrocenyl-hetaryl hydrazones [11]. In the present article we publish the synthesis and spectroscopic properties of some new ferrocenyl-pyrazoline derivatives substituted with 2-pyridyl- or 4-[phthalazin-1(2H)on-yl] group on the nitrogen atom, accomplished by the cyclocondensation of ferrocenyl-chalcone derivatives. Spectroscopic and electrochemical characteristics of several chalcone analogous ferrocenes [12a,12b] and some cyclic ferrocenyl-enones [13a,13b] were studied

☆ For part 15, see [1].
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by us earlier. For comparison of chemical and spectroscopic properties and due to the known wide-range biological activity of the phthalazine derivatives [14], the analogous bis-aryl-*N*-phthalazinonyl-dihydropyrazoles were also synthesized.

Meanwhile, our work was completed, recent publications were published on the synthesis and pharmacological properties on some pyrazolines and pyrazoles containing ferrocene moiety [7,8].

2. Results and discussion

3-Ferrocenyl-1-aryl-2-propen-1-ones (**1a**,**b**) were prepared by base-catalyzed Claisen-Schmidt condensation of ferrocenecarboxaldehyde with acetophenones according to the literature procedures [7,15,16]. In a mixture of ethanol–acetic acid–water, at reflux temperature the reaction of these compounds with 2-hydrazinopyridine (**2a**) and 4-hydrazino-phthalazinone (**2b**), respectively, resulted in *N*-hetaryl-3-aryl-5-ferrocenyl-pyrazolines (**3a**,**b** and **4b**) as new crystalline compounds in 50–75% yield (Scheme 1).

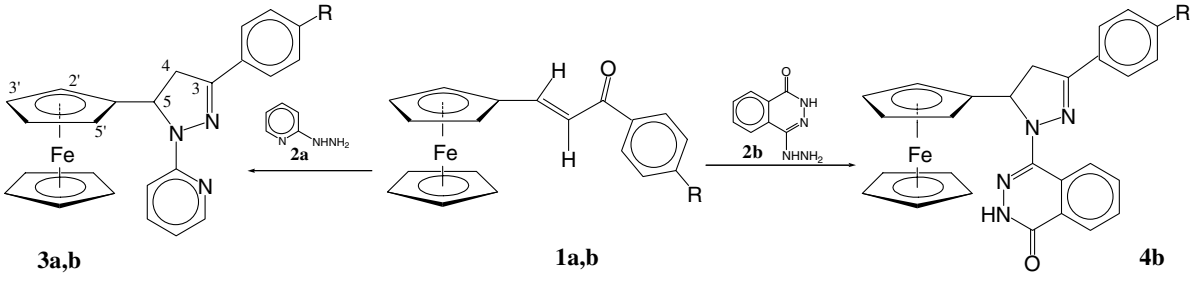
The reaction of the analogous 1-ferrocenyl-3-aryl-2-propen-1-ones (**5a**,**b**) – prepared [7,15–17] from acetylferrocene with benzaldehydes – under similar conditions with hetaryl hydrazines **2a**,**b** gave the isomeric *N*-hetaryl-3-ferrocenyl-5-aryl-pyrazolines (**6a**,**b**), but longer reaction time was needed even for partial conversion and the main products after chromatography were isolated in much lower (25–30%) yield. The significantly decreased reactivity of **5a**,**b** relative to that of **1a**,**b** can probably be attributed to the enhanced electron-releasing effect of the ferrocenyl substituent exerted on the directly attached carbonyl group (Scheme 2).

In comparison, the reaction of the corresponding 1,3-bis-arylchalcones (**7a**,**b**) with 4-hydrazinophthalazinone (**2b**) was also carried out. Applying longer reaction time (8–12 h) and dilute solution, cyclic products with pyrazoline structure (**8a**,**b**) were isolated in good yield. From more concentrated solution within 3–4 h the poorly soluble ene-hydrazones (**9a**,**b**), as simple condensation products, often spontaneously crystallised from the reaction mixture (Scheme 3).

3. Structures and spectroscopy

The ^{1}H, ^{13}C and ^{15}N NMR spectral data of the new compounds are given in Tables 1–4. These data confirm the supposed structures straightforwardly. The following additional facts can be stated:

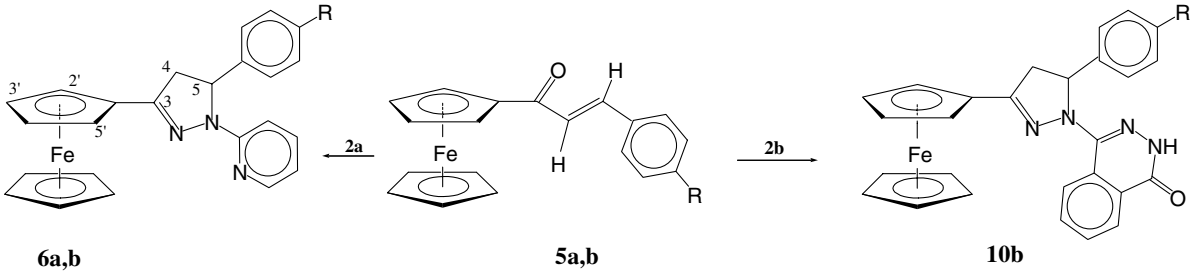
Comparing the ^{1}H NMR data of positional isomers **3a**–**6a** and **3b**–**6b**, it is sticking that one of the 4-methylene hydrogens is more shielded (3.02 and 2.98 ppm) than the other (3.73 and 3.68 ppm) for **6a**,**b**, while in **3a**,**b** no such strong shielding is observable (all shifts are in the interval of 3.60–3.75 ppm). This is due to the anisotropic effect [18a] of the *cis*-arranged 5-aryl



3a,b **1a,b** **4b**

a: R = H, b: R = OMe

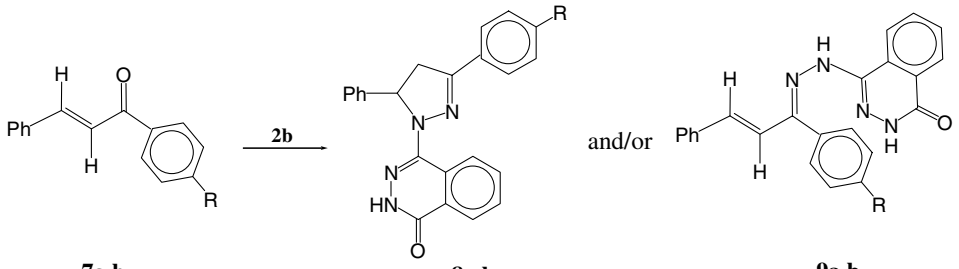
Scheme 1.



6a,b **5a,b** **10b**

a: R = H, b: R = OMe

Scheme 2.



a: R = H, b: R = OMe

Scheme 3.

Table 1
^{1}H NMR data[a] of compounds **3a**,**b**, **4b**, **6a**,**b**, **8a**,**b**, **9a**,**b** and **10b**[b]

Compound	OCH_3 s (3H)	CH_2 (Pos. 4)[c]	H-5	H-2′,5′	H-3′,4′	H-1-5 Cp[f]	H-2,6	H-3,5	H-4	H-5/3	H-6/4	H-7/5	H-8/6	NH s (1H)
		Pyrazoline ring[d]		Substituted Cp ring[e]			3-Phenyl/ anisyl group[g]			Phthalazinonyl/ α-pyridyl ring				
3a	–	3.66, 3.75	5.70	4.05, 4.55	4.07, 4.10	4.16	7.86	7.46	7.39	7.38	7.50	6.66	8.19	–
3b	3.86	3.60, 3.70	5.65	4.06, 4.50	4.05, 4.10	4.14	7.78	6.98	–	7.34	7.47	6.63	8.17	
4b	3.79	3.35, 3.87	5.51	4.31, 4.39	4.10	4.21	7.73	7.01	–	8.21	7.82	7.91	8.41	12.2
6a	–	3.02, 3.73	5.74	4.55, 4.73	4.36, 4.37	4.09	~7.3		7.23	7.35	7.50	6.60	8.04	–
6b	3.75	2.98, 3.68	5.67	4.53, 4.71	4.34, 4.35	4.09	7.21	6.83	–	7.21	7.47	6.57	8.04	–
8a	–	3.08, 3.88	5.68	~7.4[g]	7.29	7.20	7.70	~7.4[g]		8.21	7.85	7.94	8.64	12.06
8b	3.71	2.99, 3.78	5.59	7.35	7.23	7.15	7.58	6.91	–	8.15	7.78	7.91	8.58	11.98
9a	–	7.29, 7.85	6.35	~7.4[h]	7.32	7.25	~7.4[h]	7.66	7.61	8.42	7.80	7.81	7.97	11.2
9b	3.79	7.16, 8.28	6.24	7.42	7.25	7.18	7.30	7.13	–	8.17	7.78	7.84	7.94	12.0
10b	3.76	3.09, 3.52	5.59	4.59, 4.61	~4.37	4.19	7.37	6.84	–	8.40	7.75	7.85	8.69	9.99

[a] In $CDCl_3$ (**3a**,**b**, **6a**,**b**, **10b**) and (**8b**)/or DMSO-d_6 (**4b**, **8a**, **9b**) solution (for **9a** 4:1 mixture of these solvents) at 500 MHz. Chemical shifts in ppm ($\delta_{TMS} = 0$ ppm), coupling constants in Hz.
[b] Assignments were supported by HMQC and for **6a** and **8b** NOEDIF measurements.
[c] Two dd's (2 × 1H), ^2J: 16.8 (**3a**,**b**, **6a**,**b**, **8a**,**b**), 16.2 (**10b**), ^3J (upfield dd): 4.4 (**3a**,**b**, **6a**,**b**), 12.5 (**8a**,**b**), 12.2 (**10b**), ^3J (downfield dd): 11.3 (**3a**,**b**), 12.0 (**6a**,**b**), 11.1 (**8a**,**b**, **10b**), two d's (2 × 1H) for **9a**,**b**, J : 16.3.
[d] H(α), NH, and H(β), resp., in the enhydrazino group (**9a**,**b**).
[e] The H-2,6 and H-3,5 signals (~d and ~t) of the phenyl attached to the C-5 (sp^3) atom in the pyrazoline ring (**8a**,**b**, **9a**,**b**).
[f] Unsubstituted ring, for **8a**,**b** and **9a**,**b** the H-4 signal (~t) of the phenyl attached to the C-5 (sp^3) atom in the pyrazoline ring.
[g] Pos. 5 for **6a**,**b** and **10b**.
[h] Two overlapping signals.

group which must be then perpendicular to the pyrazoline ring in the preferred conformation. The similar effect can also be stated for **8a**,**b** and **10b**.

A small, but significant difference can be observed in the ^{1}H NMR chemical shift of the H's in unsubstituted Cp ring for the positional isomers **3** and **6** (0.06 ppm). Thus, the change in electronic distribution in the isomers is transferred via the sandwich bond and the Fe atom.

The measured ^{15}N chemical shifts (Table 4) demonstrate the presence of a hydrazone moiety in each compound described here.

The α-effect [18b,19] of the ferrocenyl and aryl substituents on C-3 is hardly different (1.4 and 0.8 ppm for the pairs **3a**–**6a** and **3b**–**6b**), while for the ^{13}C NMR chemical shifts of C-4 and C-5 a large differerence was observed for the isomers (for **3a**–**6a** 4.2 and 3.6 and for **3b**–**6b** 3.6 and 3.7). Because a substantial difference in the α-effect is not expectable depending on the nature of the substituted carbon, these shift differences may be originated from the field effect [18c,20] causing upfield shifts of carbons substituted by bulkier groups. In **3** and **6**, a steric hindrance between N(1)- and 5-substituents is expectable. In accordance with the aboves, the C-4 and C-5 lines are upfield shifted in **3a**,**b**, where the bulkier ferrocenyl moiety is bonded to C-3 instead of the smaller aryl group.

As a proof of the steric interaction between the substituents in Pos. 1 and 5, a significant difference (0.50 and 0.46 ppm) can be stated in the ^{1}H NMR chemical shifts of H-2′ and H-5′ for **3a** and **3b**. Due to the anisotropic effect of the heterocycle, the H-2′ (or H-5′) atom of the Cp ring lying above the plane of the heteroaromatic ring is more shielded and its signal is upfield shifted (to 4.05 ppm). This effect is absent in **6a** and **6b**. Instead, the coplanar arrangement of the Cp ring and the C=N double bond reveals in a dramatic downfield shift of this

Table 2
^{13}C NMR chemical shifts (in ppm, $\delta_{TMS} = 0$ ppm)[a] of compounds **3a**,**b**, **6a**,**b**, **8a**,**b**, **9a**,**b** and **10b**[b,c]

Compound	OCH_3	C-3	C-4	C-5	C-1′	C-2′, 5′	C-3′, 4′	C-1-5 Cp[f]	C-1	C-2,6	C-3,5	C-4	C-2/1	C-3/5	C-4/6	C-5/7	C-6/8
		Pyrazoline ring[d]			Substituted Cp ring[e]				Phenyl/anisyl group				α-Pyridyl/phthalazinonyl ring				
3a	–	150.1	40.3	57.3	89.3	66.8, 70.6	68.3, 68.4	69.0	133.0	126.4	129.1	129.5	156.1	109.9	137.5	114.7	147.6
3b	55.8	150.1	40.5	57.1	89.6	68.3, 70.4	66.9, 68.2	69.0	125.9	127.9	114.6	160.9	156.4	109.7	137.3	114.4	147.7
6a	–	151.5	44.6	61.5	77.3	67.1, 67.6	70.2, 70.4	69.7	143.6	126.1	129.2	127.6	155.7	109.1	137.5	114.1	148.1
6b	55.3	150.9	44.2	60.7	77.2	66.8, 67.2	69.8, 69.9	69.3	135.6	126.9	114.1	158.7	155.7	108.8	137.0	113.8	149.7
8a	–	153.1	42.2	64.3	142.1	127.5	129.4	128.2	132.5	127.0	129.7	130.5	144.2	126.9	132.5	134.8	128.0
8b	56.1	152.9	42.5	64.2	144.4	127.5[g]	129.4[h]	128.6	127.6	128.1	115.1	161.2	142.3	127.5[g]	132.3	133.9	129.5[h]
9a	–	152.0	124.2	135.2	136.7	127.0	128.9	128.5	131.2	130.1[g]	129.0	130.1[g]	142.7	127.2	131.8	133.3	129.3
9b	56.1	151.5	130.5	134.3	137.1	127.6	129.7	129.0	123.7	131.0	115.9	160.7	142.9	127.1	132.5	134.0	125.5
10b	55.7	153.5	44.0	63.3	76.8	67.4, 67.7	70.4[g]	69.9	133.8	128.4	114.4	159.4	145.2	127.0	131.5	133.2	128.2

[a] In $CDCl_3$ (**3a**,**b**, **6a**,**b**, **10b**) and (**8b**)/or DMSO-d_6 (**8a**, **9b**) solution (for **9a** 4:1 mixture of these solvents) at 125 MHz.
[b] Assignments were supported by DEPT (except for **3a**), HMQC and HMBC measurements.
[c] Further signals of the phthalazinonyl group: C-4 (C=O): 159.5 (**8a**,**b**, **9b**), 159.8 (**9a**), 160.3 (**10b**), C-4a: 129.3 (**8a**, **9a**,**b**, **10b**), 129.5 (**8b**), C-8a: 127.4 (**8a**), 125.2 (**8b**, **9a**), 125.8 (**9b**), 128.0 (**10b**).
[d] Carbons in α-, β- and γ-position, resp., to the sp^2 N in the enhydrazino group (**9a**,**b**).
[e] The C-1, C-2,6, C-3,5 and C-4 lines of the phenyl attached to the C-5 (sp^3) atom in the pyrazoline ring.
[f] Unsubstituted ring.
[g] Two overlapping lines.
[h] Interchangeable assignments.

signal (to 4.73 and 4.71 ppm) in *S-cis* orientation to this bond due to its anisotropic effect [18d].

The separated H,C-2′/5′ and H,C-3′/4′ signals of our ferrocenyl *N*-heterocycles due to the inherent diastereotopy (chirality center C-5) and/or the restricted rotation of the ferrocenyl moiety around the C(py)–C(Cp) bond. To prove the contribution of rotational hindrance in these signal separations we carried out variable temperature (DNMR) experiments. The ^1H NMR spectra of pyrazolines **3a** and **6b** were measured at 415 and 440 K, respectively. Only a decrease of the signal separation ($\Delta\Delta\nu$) could be observed. From $\Delta\Delta\nu$ values it can be established that the contribution of hindered rotation of the Fc group is responsible in ca. 25–30% for the chemical non-equivalence of H-2′ and H-5′ atoms. The more important reason, however, must be the diastereotopy, in accordance with the literature data [21a,21b].

Our findings on ferrocenyl macrocycles [22] containing two 1,1′-substituted ferrocene moieties bridged by two –CR=N–N=CR′– binding chains support the role of restricted rotation in signal separation. DFT calculations and DNMR measurements confirmed for these molecules, that in the conformational equilibrium the rotamers containing the –RC=N–N=CR′– binding chains coplanar to the Cp rings are strongly preferred. These molecules are symmetric without chirality centres and if they are rigid – free internal rotation of the binding chains or their parts is not possible – the chemically non-equivalence of C/H-2′,5′ and C/H-3′,4′ atom pairs were observed.

4. X-ray studies

Although chalcone **1b** is known for a long time [7,16], its X-ray study has not been published till now. We report now the single crystal analysis of **1b** and two of our new products, **3b** and **8b**. The X-ray structures are depicted in Figs. 1 and 2. The selected bond parameters can be seen in Table 6.

While there is no difference found in the Fe1–Cp distances and the parallel arrangement of the two Cp rings in **1b** and **3b**, the relative position of these rings is different, in **1b** it is staggered, in **3b**, however, it is eclipsed.

The side-chain in **1b** is in elongated conformation, the enone moiety has *S-cis* conformation and its torsion angle is 2.6(8)°. The phenyl ring is nearly coplanar: the angle between the carbonyl and the former ring is 4.0(4)°. This might suggest extended conjugation, but the bond distances does not support such an electron distribution: (C(1)–C(2) 1.333(6) Å, C(2)–C(3) 1.486(7) Å, O(2)–C(3) 1.229(6) Å, C(3)–C(4) 1.474(7) Å).

In both **3b** and **8b** the central pyrazoline rings have an envelope structure with the chiral C1 on the tip. The distances of C1 atoms from the plane of the others are 0.289(10) and 0.356(3) Å, respectively.

Table 3
Characteristic IR frequencies (cm^{-1}) of compounds **3a**,**b**, **4b**, **6a**,**b**, **8a**,**b**, **9a**,**b** and **10b** (in KBr discs)

Compound	νNH band[a]	Amide-I band	νC=N band	$\gamma C_{Ar}H$ band[b]	$\gamma C_{Ar}H$ band[c]	$\gamma C_{Ar}C_{Ar}$ band[d]	νC–O band	ν_{as} Cp–Fe–Cp and tilt of Cp
3a	–	–	1589	773	760	693	–	502
3b	–	–	1590[e]	769	830[f]	–	1246	490[g]
4b	3250–2750	1658	1588[e]	–	829	–	1250	508
6a	–	–	1589	764[h]	764[h]	705	–	483
6b		–	1588	761	828	–	1245	487
8a	3300–2700	1657	1581	–	760	693	–	–
8b	~3160	1661	1584[e]	765	820	697	1247	
9a	3365, 3250	1660	1599	779	760	704, 695[e]	–	–
9b	3310, 3145[e]	1652	1594	781	821	680	1245	–
10b	3250–2750	1656	1586	–	827	–	1251[e]	563

[a] Diffuse (**4b**, **8a**, **10b**), broad (**8b**).
[b] Pyridine (**3a**,**b**, **6a**,**b**), phenyl (**8b**, **9b**, **10b**).
[c] Mono- (**a**) or *p*-disubstituted benzene (**b**).
[d] Monosubstituted benzene.
[e–g] Splitted band with the further maxima at 1606[e], 854[f] and 508[g] (**3b**), 1607 (**4b**), 1607 (**8b**), 675 (**9a**), ~2950 broad (**9b**) and 1028 (**10b**).
[h] Two overlapping bands (very strong).

Table 4
^{15}N NMR chemical shifts[a] of compounds **8a**,**b** and **9a**[b]

Compound	N-1	N-2	N-2	N-3
	Pyrazoline ring[c]		Phthalazinone ring	
8a	163	333	276	177
8b	161	328	275	177
9a	137	317	264	174

[a] In $CDCl_3$ solution at 50.7 MHz. Chemical shifts in ppm ($\delta NH_3 = 0$ ppm).
[b] Assignments are based on ^{15}N,^{1}H-HMBC measurements.
[c] For **9a** sp^3-N (N-1) and sp^2-N (N-2).

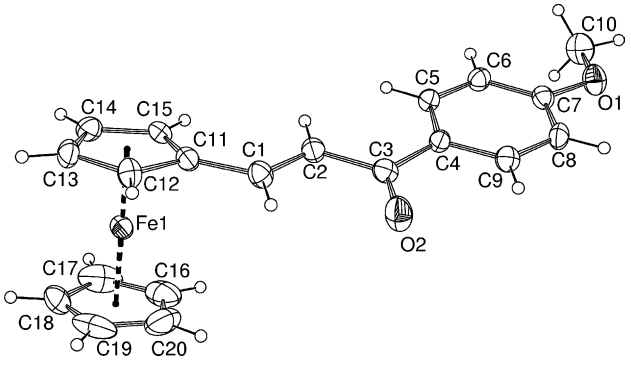


Fig. 1. The ortep diagram of **1b** (the ellipsoid probability is 30%).

The anisyl groups in **3b** and **8b**, respectively, are nearly perpendicular to the pyrazoline rings. In **3b** the least-squares planes of the pyrazoline and the closer Cp rings is 86.4(3)°. In **8b** the phenyl and anisyl rings have angles to the pyrazoline moiety of 87.7(1)° and 4.3(1)°, respectively.

In both **1b** and **3b** the main crystal building forces are the dipole–dipole and the dispersion type, second order interactions between the polar rings and the apolar ferrocenyl moieties, respectively. The distinct layers of the apolar ferrocenyl groups and the polar moieties in the crystals of **1b** run perpendicular to the *ab* plane while in the crystals of **3b** the *ac* plane of the unit cell. In **1b** in the apolar layers the ring planes of the ferrocenes of the symmetry equivalent molecules are perpendicular, while in **3b** in each apolar layer the axes of the symmetry equivalent ferrocenes are parallel and perpendicular to the axes of ferrocenes in the neighbouring apolar layer.

In the crystals of **8b**, the presence of donor N–H atom causes significant change in the crystal structure results in the formation of hydrogen bonds. The intermolecular hydrogen bonds formed between the O1 carbonyl oxygen and the NH group of $[-x+2, -y, -z+1]$ symmetry equivalent molecule, and inversely. The hydrogen bonding pattern of the crystal shows H-bonded pairs of molecules. The hydrogen bondings are showed in Table 6. The distinct layers of the polar naphtalazone moiety and the apolar rings, respectively, run parallel to the *ac* plane of the unit cell. In the polar layers, the planes of the naphtalazone moieties of the symmetry equivalent molecules are parallel. The planes of all phenyl groups are perpendicular to the *bc* plane of the unit cell (see Fig. 3).

5. Experimental

IR spectra were recorded with a Bruker IFS-55 FT-spectrometer using KBr pellets. The ^{1}H and ^{13}C NMR spectra were obtained at 500 and 126 MHz by a Bruker DRX-500 spectrometer in $CDCl_3$ or DMSO-d_6 solution, with the deuterium signal of the solvent as the lock and Me_4Si as internal standard. The standard Bruker microprogram NOEMULT.AU to generate NOE was used with a selective pre-irradiation time. DEPT spectra were run in a standard manner, using only the $\Theta = 135°$ pulse

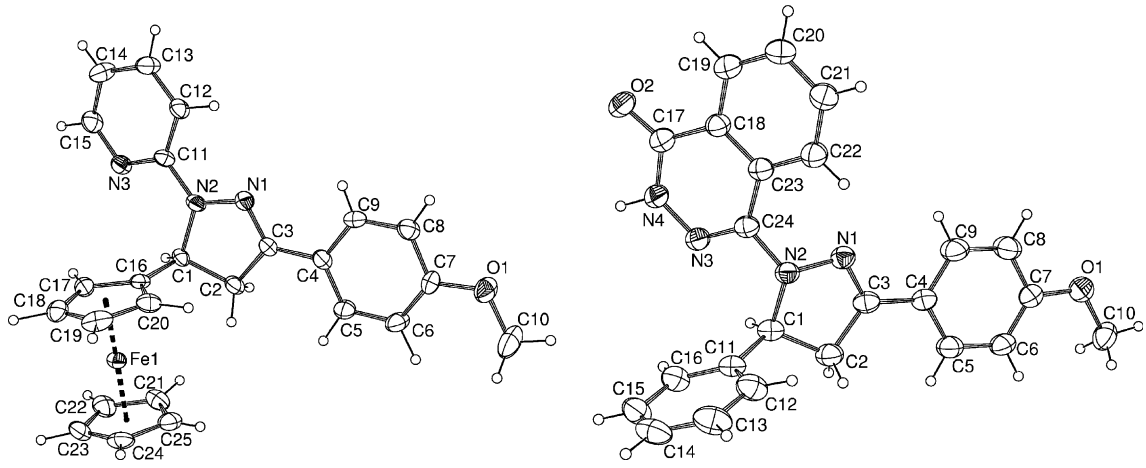


Fig. 2. The ortep diagram of **3b** and **8b** (the ellipsoid probability is 30%).

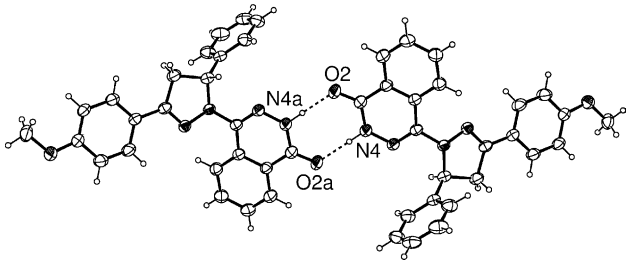


Fig. 3. Hydrogen bonds in the molecule of **8b**.

to separate CH/CH_3 and CH_2 lines phased "up" and "down", respectively. The 2D-HMQC spectra were obtained by using the standard Bruker pulse program HXCO.AU.

The X-ray measurements were made on a Rigaku AFC6S diffractometer with graphite monochromated Cu Kα radiation ($\lambda = 1.54178$ Å). The crystals were mounted on a glass fibre. Cell constants and an orientation matrix for data collection were obtained from a least-squares refinement using the setting angles of carefully centred reflections. The data were collected at a temperature of 293 K using the $\omega/2\theta$ scan technique. Data processing was carried out by use of the software supplied with the diffractometer. Structure solutions with direct methods were carried out with the teXsan Crystal Structure Analysis Package [23]. Refinements were carried out using the SHELXL-97 [24] program by the full matrix, least squares method on F^2. All non-hydrogen atoms were refined anisotropically. Hydrogen atoms were generated based upon geometric evidence and their positions were refined by the riding model. The crystallographic data for compounds **1b**, **3b** and **8b** are summarized in Table 6. Full lists of atomic coordinates, bond lengths, angles and atomic displacement parameters have been deposited at the Cambridge Crystallographic Data Centre. CCDC-257154, -257152, -257153 for compounds **1b**, **3b** and **8b**, respectively, contain the supplementary crystallographic data for this paper. These data can be obtained free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (internat.) +44-1223-336-033; e-mail: deposit@ccdc.cam.ac.uk].

TLC was performed on aluminium plates precoated with Silica Gel 60 F_{254} (E. Merck), the spots were detected visually or by UV light at 254 and 366 nm, respectively.

Table 5
Physical and analytical data on compounds **3a**, **3b**, **4b**, **6a**, **6b**, **8a**, **8b**, **9a**, **9b**

Compound	m.p. (°C)	Formula	Calculated %			Found %		
			C	H	N	C	H	N
3a	163–164	$C_{24}H_{21}FeN_3$	70.77	5.20	10.32	70.68	5.11	10.19
3b	168–169	$C_{25}H_{23}FeN_3O$	68.66	5.30	9.61	68.47	5.21	9.44
4b	287–290	$C_{28}H_{24}FeN_4O_2$	66.68	4.80	11.11	66.43	4.72	11.10
6a	180–181	$C_{24}H_{21}FeN_3$	70.77	5.20	10.32	70.54	5.23	10.29
6b	164–147	$C_{25}H_{23}FeN_3O$	68.66	5.30	9.61	68.42	5.24	9.41
8a	249–250	$C_{23}H_{18}N_4O$	75.39	4.95	15.29	75.28	4.94	15.16
8b	290–292	$C_{24}H_{20}N_4O_2$	72.71	5.09	14.13	71.97	5.05	14.02
9a	198–201	$C_{23}H_{18}N_4O$	75.39	4.95	15.29	75.35	5.01	15.19
9b	205–206	$C_{24}H_{20}N_4O_2$	72.71	5.09	14.13	72.92	5.04	14.05

Table 6
The crystal data, selected bond lengths (Å), angles (°) and torsion angles (°)

	1b	**3b**	**8b**
Crystal colour, habit	Red, needle	Orange, needle	Colourless, plate
Crystal dimensions (mm^3)	$0.12 \times 0.15 \times 0.95$	$0.15 \times 0.12 \times 0.45$	$0.27 \times 0.13 \times 0.42$
Crystal system	Monoclinic	Monoclinic	Triclinic
Space group	$P2_1/a$	$P2_1/c$	$P\bar{1}$
Lattice parameters			
a (Å)	10.550(2)	7.420(2)	8.660(2)
b (Å)	7.839(1)	16.331(2)	15.243(1)
c (Å)	19.200(1)	17.004(2)	8.486(2)
α (°)			103.86(1)
β (°)	90.817(7)	90.43(1)	105.88(2)
γ (°)			78.61(1)
Bond lengths			
N1–N2		1.369(6)	1.410(2)
N2–C1		1.480(6)	1.494(3)
C1–C2	1.333(6)	1.531(8)	1.526(3)
C2–C3	1.486(7)	1.519(8)	1.502(3)
C3–N1		1.295(7)	1.277(3)
C3–C4	1.474(7)	1.455(8)	1.468(3)
C3–O2	1.229(6)		
Angles			
C3–N1–N2		108.9(5)	108.7(2)
N1–N2–C1		113.0(4)	109.6 (1)
N2–C1–C2		100.0(4)	100.9(2)
C1–C2–C3	120.4(5)	102.9(5)	102.1(2)
C2–C3–N1		111.9(6)	113.5(2)
C2–C3–C4	119.0(5)	124.0(6)	125.4(2)
C2–C3–O2	120.0(5)		
O2–C3–C4	121.1(5)		
Torsion angles			
C1–C2–C3–O2	2.6(8)		
C1–C2–C3–C4	−177.3(5)	169.7(5)	−169.5(2)
C2–C3–C4–C5	−5.2(8)	−3.4(10)	−1.7(4)
C1–C2–C3–N1		−11.4(7)	13.0(3)
C2–C3–N1–N2		0.3(7)	1.1(3)
C3–N1–N2–C1		11.9(7)	−15.5(2)
N1–N2–C1–C2		−18.0(6)	22.3(2)
N2–C1–C2–C3		16.2(6)	−19.9(2)
Hydrogen bond			
Donor–H···Acc.			N4–H4···O2(a)
d(D–H)			0.962
d(H···A)			1.831
d(D···A)			2.793
∠(D–H···A)			178.4

Translation of symmetry codes to equiv. positions: (a)=$-x+2, -y, -z+1$.

Column chromatography was made on silica gel (E. Merck, 0.020–0.043 mesh).

4-Hydrazino-phthalazin-1(2H)-one (**2b**) was prepared, as described in the literature [25]. 3-Ferrocenyl-1-aryl-2-propen-1-ones **1a** and **1b**, resp., were obtained by condensation of ferrocenecarboxaldehyde (5 mmol) with acetophenone and 4-methoxy-acetophenone, resp. (5 mmol), in ethanol (4 cm^3), applying 10% aqueous KOH solution (4 cm^3) as base catalyst [16]. The reactions were followed by TLC (benzene/EtOAc 4/1). Products were crystallised by dissolving in methanol and by precipitating with water. Yield for **1a** ($C_{19}H_{16}FeO$) 90%, m.p. 141–142 °C, lit. m.p. 141–142 °C [16]; for **1b** ($C_{20}H_{18}FeO_2$) 87%, m.p. 153 °C, lit. m.p. 153–154 °C [16]. The analogous 1-ferrocenyl-3-aryl-2-propen-1-ones (**5a** and **5b**) were prepared by treatment with a mixture of acetylferrocene and benzaldehyde or 4-methoxy-benzaldehyde, resp., in ethanol with 10% KOH solution, as described for **1a**. Yield for **5a** ($C_{19}H_{16}FeO$) 90%, m.p. 140–141 °C, lit. m.p. 141–142 °C [26]; for **5b** ($C_{20}H_{18}FeO_2$) 87%, m.p. 151–152 °C, lit. m.p. 152–153 °C [16].

Analytical and physical data of the new compounds are given in Table 5.

5.1. 5-Ferrocenyl-3-phenyl-1-(2-pyridyl)-2-pyrazoline (*3a*)

3-Ferrocenyl-1-phenyl-2-propen-1-one (**1a**, 1 mmol) and 2-hydrazino-pyridine (**2a**, 1.2 mmol) were refluxed in a mixture of EtOH (8 cm^3), AcOH (3 cm^3) and H_2O (2 cm^3) under nitrogen. After 10 h, further **2a** (1.2 mmol) was added in EtOH (2 cm^3)–AcOH (1 cm^3) and the reflux was continued for additional 10 h, while TLC (benzene/EtOAc 5/1) indicated complete reaction. The mixture was evaporated and co-distilled several times with EtOAc and then triturated with a few EtOAc to give a yellow solid, yield 74%. Purification by column chromatography with a solvent mixture of *N*-hexane–$CHCl_3$–EtOAc (3:1:0.5) and treatment with petroleum ether afforded yellow needles of pure **3a**, yield 56%.

5.2. 5-Ferrocenyl-3-(p-methoxyphenyl)-1-(2-pyridyl)-2-pyrazoline (*3b*)

3-Ferrocenyl-1-(4-methoxy-phenyl)-2-propen-1-one (**1b**) with **2a**, in a similar procedure as described at the synthesis of **3a**, after 20 h reflux and subsequent cooling, gave dark yellow crystals of **3b**. Re-crystallisation by dissolving in EtOAc and precipitating with petroleum ether gave pure product, yield 53%.

In the mother liquor a small amount (<5%) of a by-product was indicated but not isolated.

5.3. 5-Ferrocenyl-3-phenyl-1-{4-[phthalazin-1(2H)-on]-yl}-2-pyrazoline (*4b*)

Ferrocenyl-*p*-methoxyphenyl chalcone **1b** was reacted with 4-hydrazino-phthalazin-1(2H)-one (**2b**) in a similar procedure as described above. While refluxing, yellow crystals of **5b** separated from the reaction mixture. After filtration the product was washed with methanol to give pure **5b** in 62% yield.

5.4. 3-Ferrocenyl-5-phenyl-1-(2-pyridyl)-2-pyrazoline (*6a*)

1-Ferrocenyl-3-phenyl-2-propen-1-one (**5a**, 1 mmol) was reacted with 2-hydrazino-pyridine (**2a**) as described for **3a**. During the reaction formation of significant amount of paramagnetic substances was observed. After refluxing for 20 h the reaction mixture was evaporated and co-distilled several times with EtOAc. The dark oily residue was purified by column chromatography first with chloroform and the main product repeatedly with benzene–EtOAc (4:1) as eluent. Small amount of by-products was detected but they were not further investigated. The unchanged starting material (40%) was recovered. The main product was crystallised from CH_2Cl_2/petroleum ether to give pure **6a** as orange–red crystals, yield 24%.

5.5. 3-Ferrocenyl-5-(p-methoxyphenyl)-1-(2-pyridyl)-2-pyrazoline (*6b*)

Compound **5b** was reacted with **2a**, as described above. After 30 h reflux the reaction mixture was evaporated, and the dark residue was extracted with EtOAc, dried over $MgSO_4$, evaporated and purified by column chromatography with a mixture *N*-hexane–$CHCl_3$–EtOAc (3:2:1) as eluent. The unchanged starting material (12%) was recovered. The main product was purified again by column chromatography with the same solvent mixture to give pure **6b**. Crystallisation from ether–petroleum ether afforded orange-red crystals, yield 27%.

5.6. 3,5-Diphenyl-1-{4-[phthalazin-1(2H)-on]-yl}-2-pyrazoline (*8a*)

Diphenyl-chalcone (**7a**, 2 mmol) and 4-hydrazino-phthalazin-1(2H)-one (**2b**, 2 mmol) was refluxed in a mixture of EtOH (10 cm^3), AcOH (4 cm^3) and H_2O (4 cm^3) for 8 h under nitrogen. On cooling pale yellow crystals of **8a** were separated, yield 65%. Re-crystallisation from EtOH resulted in pure product, yield 52%. From the mother liquor of the reaction gold-yellow crystals of **9a** were obtained in 12% yield.

5.7. 3-(p-Methoxyphenyl)-5-phenyl-1-{4-[phthalazin-1(2H)-on]-yl}-2- pyrazoline (*8b*)

1-*p*-Methoxyphenyl-3-phenyl-2-propen-1-one (**7b**, 1 mmol) was reacted with **2b**, as described for **8a**. After 4 h separation of solid substance was observed. Heating was continued after adding of EtOH (4 cm^3), AcOH (2 cm^3) and H_2O (1 cm^3) for further 8 h. On cooling and partial evaporation pale yellow crystals of **8b** were separated in 77% yield. Re-crystallisation from ethanol afforded pure product in 61% yield.

5.8. 1,3-Diphenyl-2-propen-1-one {4-[phthalazin-1(2H)-on]-yl} hydrazone (*9a*)

1,3-Diphenyl-chalcone (**7a**, 4 mmol) and 4-hydrazino-phthalazin-1(2H)-one (**2b**, 4 mmol) was refluxed in a mixture of EtOH (20 cm^3), AcOH (8 cm^3) and H_2O (8 cm^3) under nitrogen for 4 h. The separated gold-yellow crystals of **9a** after cooling were filtered and washed with EtOH–water (1:1), yield 75%. Crystallisation was made by dissolving the crude product in $CHCl_3$, then ethanol was added to the solution. Partial evaporation below 30 °C gave pure product, yield 63%.

5.9. 1-p-Methoxyphenyl-3-phenyl-2-propen-1-one {4-[phthalazin-1(2H)-on]-yl} hydrazone (**9b**)

Reaction of **7b** with **2b**, as described for **9a**, resulted in crude **9b** in 90% yield. After recrystallisation pure product was obtained in 71% yield.

5.10. 3-Ferrocenyl-5-(p-methoxyphenyl)-1-{4-[phthalazin-1(2H)-on]-yl}-2-pyrazoline (**10b**)

1-Ferrocenyl-3-(*p*-methoxyphenyl) 2-propen-1-one (**5b**, 1 mmol) was reacted with 4-hydrazino-phthalazin-1(2H)-one (**2b**, 1.2 mmol) in a mixture of EtOH (16 cm^3), AcOH (6 cm^3) and H_2O (4.5 cm^3). After 10 h reflux 0.8 mmol **2b** was added and refluxing was continued for further 20 h. After evaporation the dark oily residue was purified by column chromatography with eluents benzene-hexane 2:1, then benzene and finally with benzene–EtOAc 4:1. The main product was purified again by chromatography using hexane–EtOAc 3:2 → 2:3 mixture as eluent. By-products (less than 5%) were not investigated. Crystallisation of the main product from ether–petroleum ether resulted in dark yellow crystals, yield 30%.

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