

ACID-CATALYSED INTRAMOLECULAR MICHAEL ADDITION
OF 1-ACYL-1'-CINNAMOYLFERROCENES. PROOF OF THE STRUCTURE
OF 2-SUBSTITUTED 3-PHENYL[5]FERROCENOPHANE-1,5-DIONES

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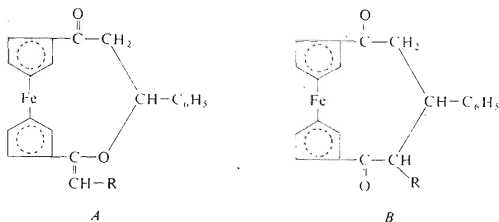
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Received December 22nd, 1973

Acid-catalysed intramolecular Michael addition of 1-acyl-1'-cinnamoylferrocenes (acyl = propionyl or X-phenylacetyl) affords a mixture of *threo* and *erythro* 2-substituted 3-phenyl[5]ferrocenophane-1,5-diones. The structure of the products was confirmed by PMR-spectroscopy.

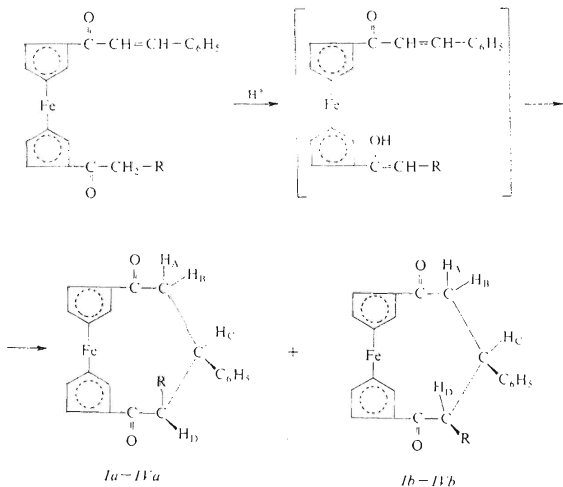
Base-catalysed intramolecular Michael addition of 1-acyl-1'-cinnamoylferrocenes and condensation of 1,1'-diacylferrocenes with aldehydes received considerable attention¹⁻³. Mashburn and collaborators⁴ assumed that the base-catalysed intramolecular Michael addition of 1-acetyl-1'-cinnamoylferrocene affords a cyclic ether (*A*, R = H) arising by cyclisation of the enol form of 1-acetyl-1'-cinnamoylferrocene. However, it was found later^{5,6} that this reaction gives 3-phenyl[5]ferrocenophane-1,5-dione (*B*, R = H) and not the cyclic ether *A* which in fact was never observed in any reaction mentioned above. It may be anticipated, that in the acid-catalysed Michael addition the first step should be the enolisation of 1-acyl-1'-cinnamoylferrocene which could lead to [5]ferrocenophane-1,5-dione derivatives (*B*) as well as to the cyclic ether *A*. In order to gain information about the effect of the acidity



of the α -hydrogens on the reaction course, we studied the reaction of various 1-acyl-1'-cinnamoylferrocenes. It was also of interest whether 1-acyl-1'-(2-methyl-3-phenyl-2-propenoyl)ferrocene undergoes the acid-catalysed Michael addition and if so, whether the cyclic ether *A* will be present among the products.

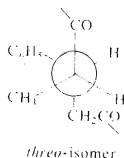
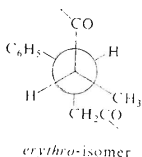
We found that the reaction affords various amounts of the isomeric 2-substituted 3-phenyl[5]ferrocenophane-1,5-diones (*Ia-VIa* and *Ib-VIb*) but in no case the cyclic ether *A*. Predominant products of the reaction are *threo*-isomers (lower melting isomers); this is in contrast with the results of the base-catalysed cyclisation¹ which affords mainly *erythro*-isomers (higher melting isomers). In the cyclisations of 1-X-phenylacetyl-1'-cinnamoylferrocenes the ratio of the arising stereoisomers is affected only very little by the substituent X. 1-Acetyl-1'-(2-methyl-3-phenyl-2-propenoyl)ferrocene, as well as 1-propionyl-1'-cinnamoylferrocene, is cyclised in a nearly quantitative yield, with *threo*-isomer predominating. The identity of products of the acid-catalysed reaction with products of the base-catalysed condensation was confirmed by mixed melting points of the mixture (no depression), by IR-spectra and by PMR-spectra. Since the derivatives *Ia-VIa* were almost insoluble in CDCl_3 , good spectra were obtained and interpreted only in the case of the derivatives *Ib-VIb*.

PMR-spectrum of the derivative *VIb* (in CDCl_3) (Fig. 1) shows phenyl protons (*m*, 5 H) at $\sim 7.4\delta$, ferrocenyl protons at 4.83δ (*m*, 4 H_a) and at 4.75δ (*m*, 4 H_β)



a CH_3 -doublet at 0.98δ and a multiplet (1 H), corresponding to $-\text{CHC}_6\text{H}_5$ (4.31δ). The spectrum exhibits also two multiplets, one corresponding to 2 H and the other to 1 H. According to an analysis of the corresponding INDOR spectra, the first multiplet is due to one of the protons of >CH_2 group and to the proton of the $-\text{CHCH}_3$ group. The second multiplet corresponds to the second proton of the >CH_2 group. The spectral parameters obtained by analysis of this 4-spin system ($\delta_A = 3.26$, $\delta_B = 2.57$, $\delta_C = 4.31$ and $\delta_D = 3.19$; $J_{AB} = 13.6$ Hz, $J_{AC} = 12.3$ Hz, $J_{BC} = 3.9$ Hz and $J_{DC} = 5.2$ Hz) are in accord with those of substituted cyclohexanones⁷. It follows from the value of the interaction constant J_{DC} that the compound has *threo*-configuration.* Although it was not possible to measure the spectrum of the corresponding higher-melting derivative in CDCl_3 , we nevertheless assume that the higher-melting compound is *erythro*-isomer. Analogically, we assigned *threo*-configuration to all the lower-melting isomers and *erythro*-configuration to all higher-melting compounds. This assignment is substantiated also by the fact that heating of the lower-melting isomers in an alkaline medium affords higher-melting isomers¹ which is in accord with the steric strain due to bulky substituents on the neighbouring carbon atoms in *threo*-isomers.

The PMR-spectra of compounds *Va* and *Vb* in CF_3COOH were also measured. Although the signals of these spectra are widened, which could be caused by partial oxidation of ferrocene in this medium or by the presence of keto-enol tautomers, the spectra of the *threo* and *erythro* isomer differ substantially. The signal of the aromatic proton which is between the $-\text{OCH}_3$ group and the bridge, is located in the spectrum of the *threo*-isomer at 6.48δ (broad singlet) whereas in the spectrum of the *erythro*-isomer it is found at 6.7δ (multiplet). In the region of the ferrocene protons the *threo*-isomer exhibits two complex multiplets: this indicates that the cyclopentadiene nuclei are equivalent (one multiplet H_α , the other one H_β). The spectrum of the *erythro*-isomer exhibits (besides multiplets) a broad singlet (approximately 4 H), indicating a magnetic non-equivalence of the cyclopentadiene nuclei. The isomers differ*substantially also in the position of the $-\text{OCH}_3$ singlet.



* As a result of a slight rotation of the cyclopentadiene rings the conformation of the bridge is substantially altered and therefore it is more appropriate to denote the compounds *threo* and *erythro* rather than *cis* and *trans* (as was done in our previous work¹).

The chemical shift of the $-\text{OCH}_3$ group in the *threo*- and *erythro*-isomers is 3.69δ and 3.87δ , respectively. The lower value for the *threo*-isomer witnesses that the $-\text{OCH}_3$ group is shielded by π -electrons of the benzene nucleus. According to Drei-

TABLE I
2-R-3-Phenyl[5]ferrocenophane-1,5-diones from the Cyclisation of 1-Acyl-1'-cinnamoylferrocenes

Compound ^a	R	<i>erythro</i> -Isomer		<i>threo</i> -Isomer	
		m.p., °C ^b	yield, %	m.p., °C ^b	yield, %
<i>I</i>	C_6H_5	^c	17	218–219	41
<i>II</i>	3- FC_6H_4	^c	49	198–200	48
<i>IV</i>	4- FC_6H_4	^c	13	189–191	63
<i>IV</i>	3- $\text{CH}_3\text{C}_6\text{H}_4$	292–295	25	186–188	40
<i>V</i>	3- $\text{CH}_3\text{OC}_6\text{H}_4$	300–302	16	192–194	45
<i>VI</i>	CH_3	293–293.5	15	220–221	83

^a *1a–VIa* are *erythro*-isomers, *1b–VIb* are *threo*-isomers. ^b Melting points of all compounds are in accord with constants published in ref.¹. ^c Does not melt below 360°C.

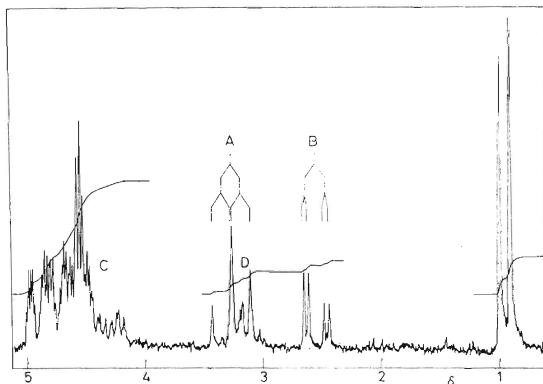


FIG. 1
NMR-Spectrum of *IVb* in CDCl_3

ding models, this situation is possible only if both carbonyl groups are in a *syn*-conformation. Such an arrangement, in which there is no internal strain due to non-bonding interaction of bulky groups, is possible only in the *threo*-isomer.

EXPERIMENTAL

All the starting 1-acetyl-1'-cinnamoylferrocenes were prepared by acetylation of cinnamoylferrocene with corresponding acyl chlorides according to ref.¹. 1-Acetyl-1'-(2-methyl-3-phenyl-2-propenoyl)ferrocene was synthesized by treatment of (2-methyl-3-phenyl-2-propenoyl)ferrocene with acetyl chloride². The melting points were determined on a Kofler block in sealed capillaries. The yields, based on the starting 1-acyl-1'-cinnamoylferrocene or on 1-acetyl-1'-(2-methyl-3-phenyl-2-propenoyl)ferrocene, are given in Table I.

The PMR-spectra were measured in CDCl₃ and CF₃COOH solutions, concentration 7–10%, on a Tesla BS 487 A, 80 MHz instrument using tetramethylsilane as the internal standard (3 vol.%) The accuracy of the shift was ± 0.2 Hz and the accuracy of interaction constants ± 0.4 Hz.

Cyclisation of 1-Acyl-1'-cinnamoylferrocenes

A mixture of glacial acetic acid (20 ml) and 96% sulphuric acid (5 ml) was added under stirring to a cooled mixture of 1-acyl-1'-cinnamoylferrocene (0.1 mol) and glacial acetic acid (60 ml) in the course of 30 minutes. The mixture was stirred for 24 hours, poured on ice and extracted with dichloromethane. The organic layer was washed with water, dried (Na₂SO₄) and taken down. The residue was mixed with benzene and the insoluble portion filtered off, washed with benzene and dried, affording thus the *erythro*-isomer (*Ia*–*Va*) in 9–25% yield. The benzene solution was chromatographed on a silica gel column. Elution with benzene afforded in 40–83% yield as the first fraction *threo*-isomer (*Ib*–*Vb*) which was crystallized from acetone–light petroleum (9:1). Subsequent fractions afforded the unreacted 1-acyl-1'-cinnamoylferrocene (6–13%).

The *erythro*-isomer *Vla*, arising in the cyclisation of 1-propionyl-1'-cinnamoylferrocene, was soluble in benzene and therefore it was obtained only in the chromatographic separation as the second fraction. No starting 1-propionyl-1'-cinnamoylferrocene was isolated. Cyclisation of 1-acetyl-1'-(2-methyl-3-phenyl-2-propenoyl)ferrocene, which was carried out under the same conditions as described above, afforded *erythro*-isomer *VIIa* and *threo*-isomer *VIIIb* in 14% and 82% yield, respectively.

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Translated by M. Tichý.