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THE STEREOCHEMISTRY, AND RING-CLOSURE AND RING-OPENING REACTIONS OF THE FERROCENOPHANE ETHERS.[*1]

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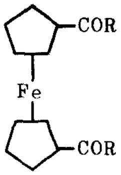
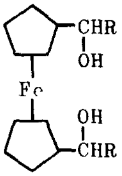
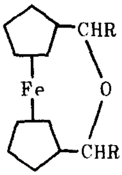
Dimethyl- and diphenyl-ferrocenophane ethers have been obtained from 1,1'-diacylferrocene via diols by reductive intramolecular dehydration-cyclization, which has been reported by several groups,1) but there have been no reports concerning studies on these stereoisomers and reaction mechamisms. Very recently, Pauson et al.2) showed experimentally the presence of two isomers in dimethyl- and diphenyl-ferrocenophane ethers (IIIA and IIIB) but did not make assignment of each steric form.



(IA) R=CH_3
(IB) R=C_6H_5



(IIA-a,b) R=CH_3
(IIB) R=C_6H_5



(IIIA-a,b) R=CH_3
(IIIB-a,b) R=C_6H_5

We reinvestigated these problems and we separated the diol (IIA) and the ethers (IIIA and IIIB), into two isomers, and estimated the conformations mainly by means of NMR spectra. Further, we investigated in detail the ring-closure and ring-opening reactions between the alcohols and the ethers through stereochemical consideration, and their reaction mechanisms are proposed.

[*1] All the compounds described with chemical formulae gave satisfactory analytical data. Melting points are uncorrected. NMR spectra were measured in $CDCl_3$(60 Mc) with TMS as internal standard unless otherwise noted.

The alcohol (IIA), m.p. 70-71°, was obtained by reduction of 1,1'-diacetylferrocene (IA) with $LiAlH_4$ in tetrahydrofuran, which was already reported.1a-d,3) On repeated recrystallization from hexane, the alcohol was obtained as yellow needles, m.p. 99.5-100.5° (IIA-a). On the other hand, the recrystallization mother liquid was chromatographed on alumina and the earlier parts of broadening band of the alcohol was recrystallized from hexane to give orange-yellow needles (IIA-b), m.p. 86-86.5°. Consequently the alcohol (IIA), m.p. 70-71°, described in earlier literature,3) is certainly a mixture of two isomers.

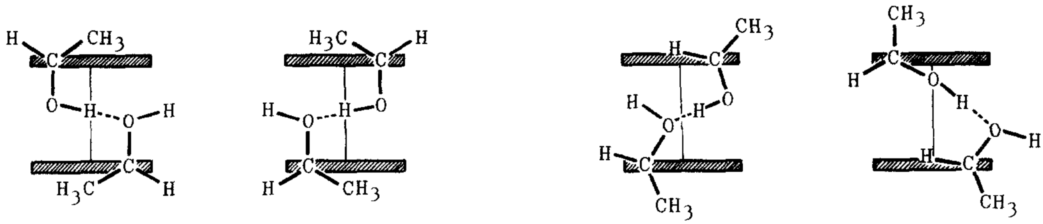
Comparison of the NMR spectra of (IIA-a) and (IIA-b), as given in Table I, shows that the methyl protons are shielded by 0.04 p.p.m., while the methine proton is deshielded by 0.07 p.p.m. in the isomer (IIA-a) than in (IIA-b). Such an interesting difference in the chemical shift suggests conformational distinction between (IIA-a) and (IIA-b), where the relative position of methyl and methine group towards magnetic anisotropic cyclopentadienyl group4,5) might be different between these two alcohols.

Table I. Chemical shifts (τ-value) of the NMR spectra.

	IIA-a a)	IIA-b a)	IIB	IIIA-a	IIIA-b	IIIB-a	IIIB-b
$-CH_3$	8.66(d)	8.62(d)	——	8.48(d)	8.54(d)	——	——
$-CH$	5.39(q)	5.46(q)	4.55(s)	6.20(q)	5.68(q)	4.95(s)	4.53(s)

a) in CCl_4

Fig. 1. Conformation of racemic and meso isomers of IIA.



(1a) (1b) (2) (3)

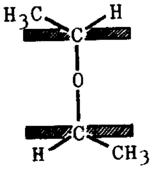
rac. meso

Intramolecular hydrogen bonding is considered as a factor causing a specific more favourable conformation in each stereoisomer. On consideration of the most stable conformation on the basis of HGS-molecular model (Fig. 1), it was found that the effect of the induced field caused by the anisotropy of the cyclopentadienyl ring[5,6] should deshield the methine proton on *meso* form relative to that on *racemic* form, but that the effect would contribute reversely for methyl protons. Therefore, it was assumed that the alcohols (IIA-a) and (IIA-b) had *meso* and *racemic* forms, respectively.

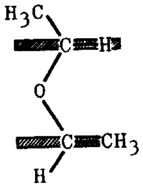
The diphenyl alcohol (IIB), prepared by the reduction of dibenzoylferrocene (IB) with LiAlH$_4$ came as a yellow powder, m.p. 134.5°-136°.[7] In NMR spectrum of (IIB) the absorption for methine proton appeared as only one peak at 4.55τ.

Treatment of the two diols (IIA and IIB) with dil. HCl easily produced an ether ring by dehydration-cyclization. Each of the ferrocenophane ethers (IIIA and IIIB) was separated into two isomers by chromatography on alumina with hexane as an eluent. The ethers (IIIA) came in orange-yellow plates (IIIA-a), m.p. 108.5-109°, and yellow prisms (IIIA-b), m.p. 107.5-108°.

Comparison of the NMR spectra between (IIIA-a) and (IIIA-b) showed that the doublet absorption for methyl protons and quartet for methine proton in (IIIA-a) appeared at a lower field region by 0.06 p.p.m. and at a higher field region by 0.52 p.p.m., respectively, than those of the ether (IIIA-b). In a manner similar to the case of the alcohol (IIA), each form of the two isomers can be assumed from these differences in the chemical shift. Since the movement of substituents is considerably fixed by the ether bond, favorable conformation can be considered with less difficulties than in the case of the alcohol (IIA). Conformation in *trans* and *cis* isomers are as follows:

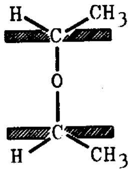


(4)

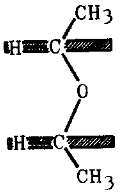


(5)

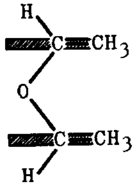
trans



(6)



(7)



(8)

cis

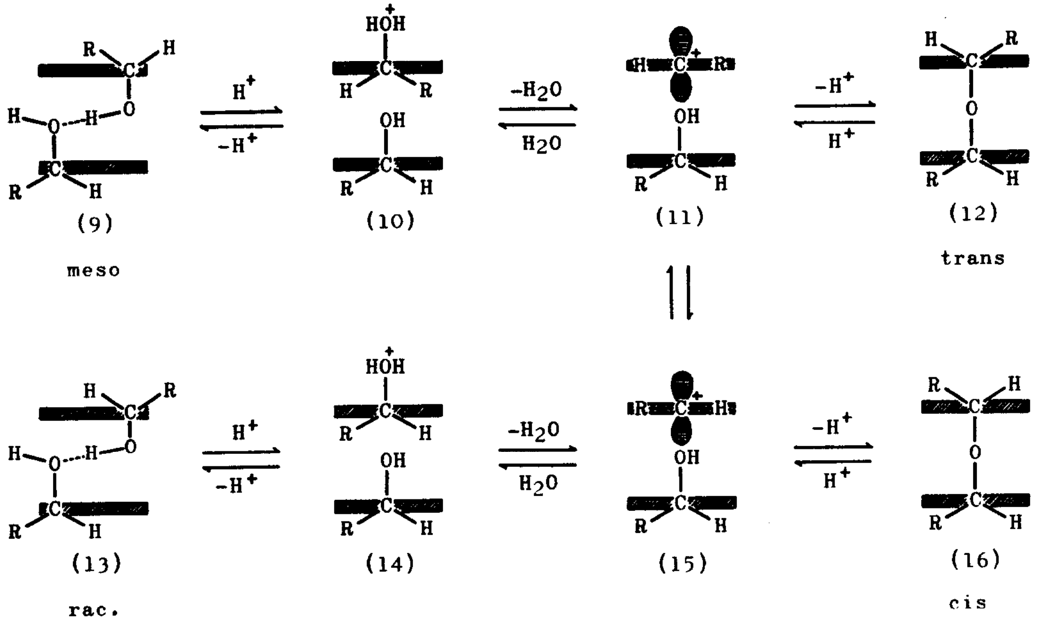
Considering the steric hindrance and the strain of C-O-C bond, more favorable conformation should be the form (4) for the *trans* isomer and the form (7) for the *cis* isomer. It has been proved that the isomer (IIIA-b), whose methine proton resonances at a lower field region, is the *cis* isomer and, consequently, another ether (IIIA-a) is the *trans* isomer.

Two isomers were also obtained in diphenylferrocenophane ether (IIIB), the one come as yellow needles (IIIB-a), m.p. 197-197.5°, and the other (IIIB-b), m.p. 194.5-195.5°. In the NMR spectra of these ethers (IIIB-a and IIIB-b), the absorption for phenyl group is not very distinguishable between the two isomers, but the chemical shift of the absorption for methine group is considerable different; the τ values of (IIIB-a) and (IIIB-b) were 4.95 and 4.53, respectively. It is resonable that anisotropy of the phenyl group contributes in nearly equal degree to both methine protons of *trans* and *cis* ethers. Therefore, by the same consideration as in the case of dimethylferrocenophane ether (IIIA), the ether (IIIB-a) and (IIIB-b) should be *trans* and *cis* isomers, respectively.

There are some interesting differences in the chemical shifts and patterns of cyclopentadienyl ring proton absorptions between two isomers in the alcohol (IIA), the ether (IIIA), and (IIIB). The analysis and discussion of these spectra will be made in a forthcoming paper.

We also investigated the ring-closure reaction of the alcohol compounds and the ring-opening reaction of the ether compounds. The ring-opening reaction of the ethers was completed by treating them with acidic alumina in benzene for a few days by which they were converted into the corresponding alcohols. In the compound whose substituent is a methyl group, the ring-closure and ring-opening reactions proceeded almost stereospecifically; *meso*-alcohol (IIA-a) $\rightleftharpoons$ *trans*-ether (IIIA-a), and *rac*.-alcohol (IIA-b) $\rightleftharpoons$ *cis*-ether (IIIA-b). In the case of phenyl as a substituent, however, it canot be said that the reaction was exceedingly stereospecific. The ring-closure reaction of the alcohol of m.p. 136° gave a mixture of *trans* and *cis* isomers, whose ratio was not always constant. The ring-opening reaction of the *cis*-ether gave the alcohol in about 15% yield, with (IIIB-a) in 15-20%, besides the recovery of the starting (IIIB-b). The ring-opening of (IIIB-a) was not easier than the reaction of (IIIB-b). The yield of the alcohol was 5%, and the *cis*-ether was obtained in about 7% yield, together with the recovery of the starting *trans* isomer.

From the above experimental facts, the reaction mechamism would be presumed as follows:



In order to explain the formation of a stereoisomer which is not the original ether in the ring-opening reaction of diphenylferrocenophane ethers, it seems reasonable to consider, also in this reaction the presence of α-ferrocenylcarbonium ion as an intermediate, which was proposed by Cais and Richards, and their co-workers,5,8) and that two isomeric intermediate cations are in equilibrium. The direction of the equilibrium probably depends on the steric stability of the cations and electronic effect of the substituent. Since the phenyl group is more likely to supply a flow of electrons towards the positively charged carbinyl carbon than the methyl group,5) the interaction between the unoccupied p-orbital of the cation center and the non-bonding orbital of the iron atom is small when the phenyl group is attached to the carbinyl carbon, so that the carbonium ion might be able to invert considerably easily into another form due to the rotation around the carbinyl to the ring bond. When R is CH_3, the ring-closure and -opening reaction proceeded almost stereospecifically as described already, but also gave another kind of the ether, even though its yield was small. Accordingly, the equilibrium (11) $\rightleftharpoons$ (13) might reasonably exist also in this case.

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