

SYNTHESIS OF P-FERROCENYLBENZOIC ACID DERIVATIVE WITH THIOUREA

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Abstract

This article presents the results of studies on the synthesis of a compound of p-ferrocenylbenzoic acid with thiourea. Based on a comparative analysis of the results of IR spectroscopic data and quantum-chemical calculations, it is shown that the synthesized compound has a heteroannular 1, 1'-disubstituted structure.

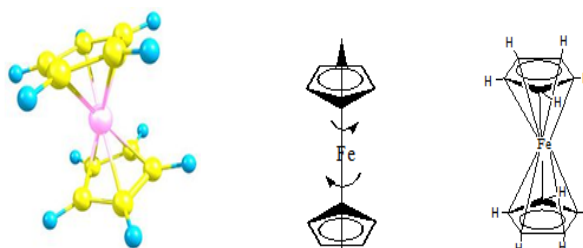
Keywords: ferrocene, diazotization reaction, p-ferrocenylbenzoic acid, urea, 1- (4-carboxyphenyl) -1'-N-ferrocenylcarboxamide, quantum-chemical calculation of the IR spectrum.

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INTRODUCTION

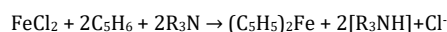
Ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$) is the first representative of organometallic compounds belonging to a number of metallocenes. Its structure was determined as a result of the research of R. Woodward, E. Fisher and D. Wilkinson and is

formed from an iron atom located in the center of the molecule between two parallel cyclopentadienyl rings. Compounds of this structure, presented below are called sandwich (R. Woodward) [1].

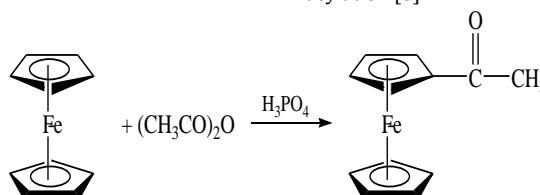


Ferrocene is a pale yellow compound with a peculiar smell, a density of 1.107 g/cm^3 at (0°C) , 1.490 g/cm^3 at (20°C) , a melting point of 172.5°C and a boiling point of 249°C . The structure of ferrocene was proved by spectroscopic and crystallographic methods [2,3].

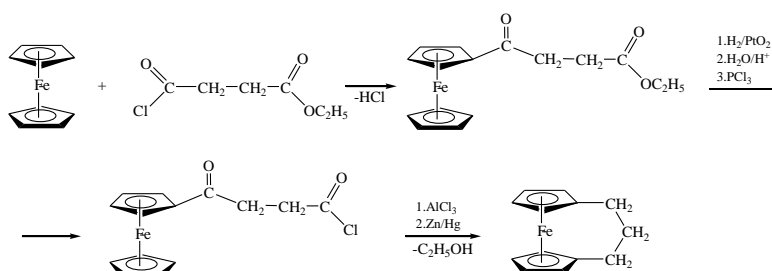
Ferrocene is most often synthesized by the interaction of FeCl_2 with cyclopentadiene in the presence of tertiary amines [4]:



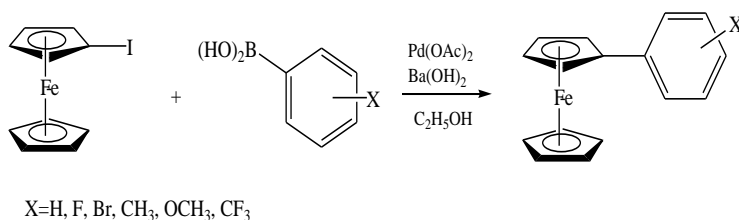
Due to the fact that ferrocene is a non-benzoic substance of aromatic nature with a higher chemical activity compared to benzene, many of its derivatives have been synthesized since its discovery, which have found application in various fields. For example, ferrocene in the presence of phosphoric acid under the action of acetic anhydride easily undergoes acylation [5].



Using the acylation reaction, two cyclopentadienyl ferrocene rings can be linked together [6]:

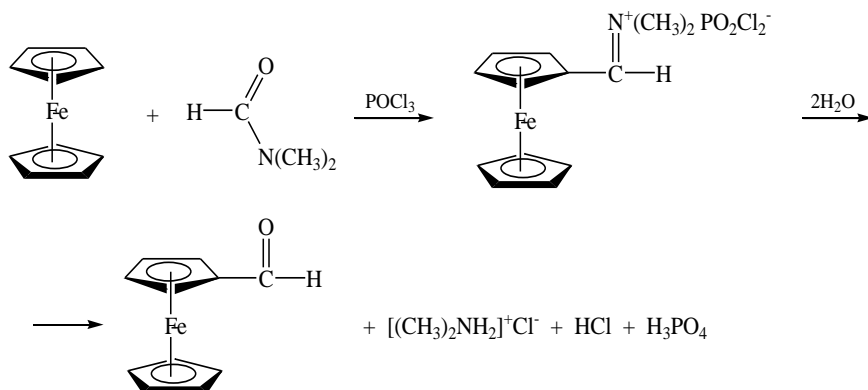


In the synthesis of arylferrocenes, iodoferrocene can be used [7].

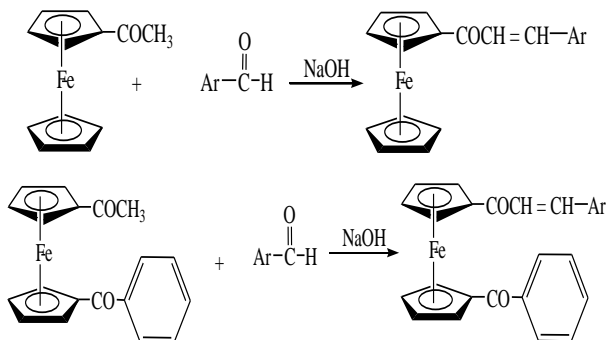


Substituted ferrocenes are oxidized with manganese (IV) oxide or chromic acid esters in solvents such as chloroform, dichloroethane, etc. In this way, ferrocenyl aldehydes with

various substituents are obtained. Ferrocenylaldehyde is obtained by the formation of ferrocene by the Vilsmeier reaction [8]:

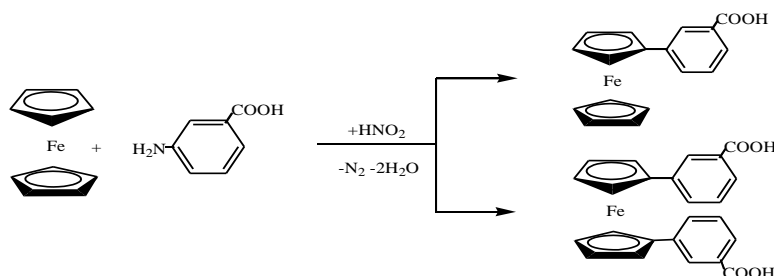


A study of the aldol condensation of acetylferrocene and 1-acetyl-1-benzoylferrocene with various aromatic aldehydes in the presence of alkali showed the low reactivity of acetylferrocene as compared to 1-acetyl-1-benzoylferrocene [9]:



Electrophilic substitution reactions occurring due to mobile hydrogen atoms of aromatic cyclopentadienyl rings are important. To carry out the substitution of these hydrogen atoms with m-aminobenzoic acid, we used the diazotization reaction in ethyl ether using sodium nitrite and hydrochloric

acid. To break down non-excessive nitrous acid at the end of the reaction, a mixture of sodium acetate and urea was added to the reaction system. The result is a mixture of mono- and disubstituted products:

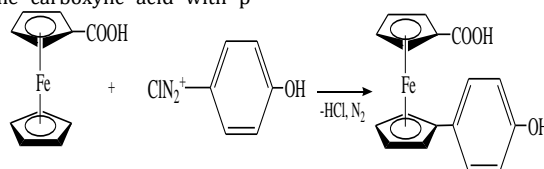


Such syntheses were also carried out with o- and p-aminobenzoic acids to give the corresponding compounds. As a result of the reaction, monoferrocenylbenzoic acids are mainly formed. Heteroanular diacids are formed in small quantities as by-products. The reaction is carried out in an

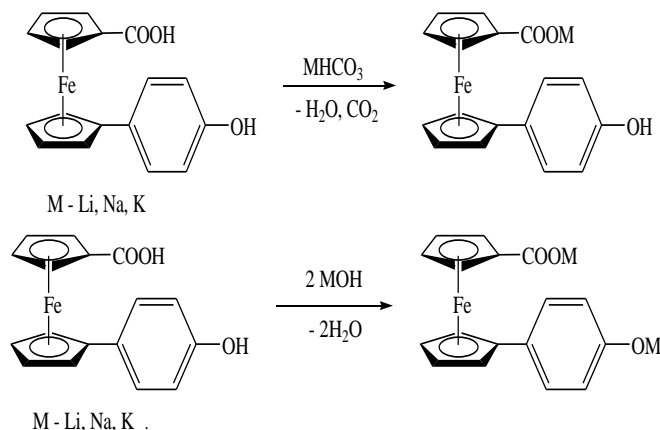
acetic acid medium. The possibility of carrying out this reaction in an environment of acetone, halogenated hydrocarbons and aqueous-ether solution was shown in [10].

In order to create new biostimulating derivatives of ferrocene, an arylation reaction of ferrocene carboxylic acid with p-

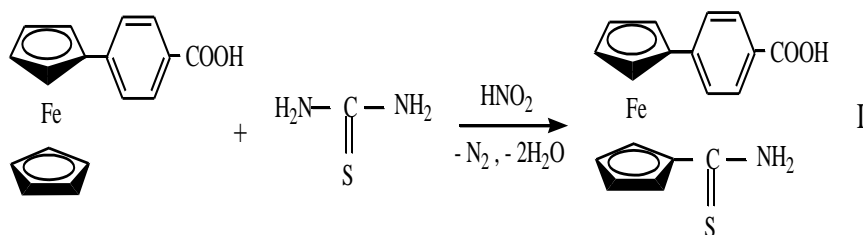
aminophenol was carried out:



1'- (p-hydroxyphenyl) ferrocene carboxylic acid is slightly soluble in water, and its water-soluble mono- and disubstituted salts with alkali metals were obtained by the following schemes:



Using thiourea in place of aminophenol in the above diazotization reaction, we attempted to synthesize a product of ferrocenylbenzoic acid with thiourea:



MATERIALS AND METHODS

150 ml of distilled water, 150 g of ice, 2.36 g (0.01 mol) of p-aminobenzoic acid and 10 ml of concentrated hydrochloric acid are introduced into a 500 ml flask equipped with a mixer. The flask with the mixture is installed in an ice bath. 3 g of sodium nitrite solution dissolved in 50 ml of water is added dropwise to the mixture over a hour with vigorous stirring. After that, the ice bath is replaced by a water bath. 3.72 g (0.02 mol) of ferrocene are dissolved in 150 ml of diethyl ether and added to the mixture, which is stirred for 3.5 hours at a temperature of 34 ° C. The mixture is then transferred to a separatory funnel to separate the ether and water parts. The aqueous portion is washed three times with diethyl ether. The ether parts are collected together, washed three times with distilled water. Then a 5% sodium hydroxide solution is added. Separated into ether and alkaline layers. An alkaline layer is isolated and a 2% hydrochloric acid solution is added. In this case, a precipitate of pale red-brown color falls. The precipitate was separated by filtration.

Synthesis of 1-(4-carboxyphenyl)-1'-N-ferrocenylcarboxamide (I).

This synthesis is carried out according to a method similar to the preparation of p-ferrocenylbenzoic acid. In this case 1.36 g (0.01 mol) of thiourea and 11.0 ml of concentrated hydrochloric acid are added instead of p-aminobenzoic acid, and 3.06 g (0.01 mol) dissolved in 100 ml of diethyl ether is added to the place of the ferrocene solution p-ferrocenylbenzoic acid. Product yield 42% (relative to p-

ferrocenylbenzoic acid); mp = 131-132 ° C; Found: Fe 15.25%; calculated for C₁₈H₁₅O₂NSFe: Fe 15.34%. The iron content was determined by atomic absorption spectroscopy on an Aurora trace AI1200 spectrophotometer.

RESULT AND DISCUSSION

Today, the methods of quantum chemical calculation and analysis of the mechanisms of complex chemical processes using fast computers are rapidly developing. There was an opportunity to theoretically study the mechanism of a chemical reaction, the product yield, the structure of the primary and formed substances, their spectroscopic parameters.

In this work, we theoretically substantiate the structure of product (I) using the method of quantum chemical calculation. A quantum-chemical calculation of the optimization of the structure, energy and spectroscopic parameters of the possible isomers of compound (I) was carried out using the Gaussian 98 software package using the 3-21G basis of the DFT / B3LYP hybrid method.

The structure of a disubstituted derivative of the diazotization reaction between m-ferrocenylbenzoic acid and thiourea is given in [11]. Based on this, structure diagrams of possible isomers of the diazotization reaction product between p-ferrocenylbenzoic acid and thiourea (I) are compiled, which are shown in Fig. 1 from a position perpendicular to the axis with respect to the plane of the cyclopentadienyl (Cp) ring. In the figure, the second ring Cp is visible behind the first.

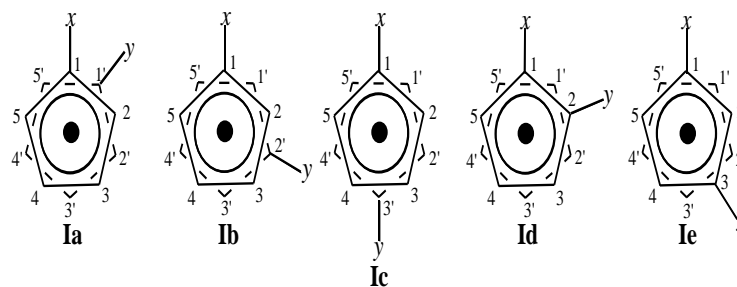


Figure 1. Type of models of possible isomers Ia, Ib, Ic, Id and Ie of substance I along the perpendicular axis with respect to the hollow of the cyclopentadienyl ring. x is 4-carboxyphenyl (-C₆H₄COOH); y is aminothiocabonyl (-C(S)NH₂); - Fe + 2 cation. 1-5 carbon numbers in the ring of the first cyclopentadienyl ferrocene; 1'-5' carbon numbers in the ring of the second cyclopentadienyl ferrocene.

In order to determine the structure of product (I), the Hartree energies (EH) of the optimized structures Ia, Ib, Ic, Id and Ie were calculated using the 3-21G basis of the DFT / B3LYP hybrid method of the Gaussian 98 software package, and the differences (ΔE) of energies were determined. From the data in table 1 it is seen that the energy value of the isomer Ia is the

smallest in comparison with other isomers. Thus, the 1,1'-disubstituted Ia isomer I of the substance is energetically and thermodynamically more stable compared to others. From this point of view, we can conclude that the main product of thiourea with p-ferrocenylbenzoic acid in structure corresponds to structure Ia.

Table 1. Hartree energies of optimized structures of possible isomers of substance I and differences between them

Position	Substance	Numbers atoms substituted carbon of	EXart, KJ / mol	ΔE , (kJ)
Heteroannus	Ia	1, -1'	-6690481.285	0
	Ib	1, 2'	-6690480.292	0.993
	Ic	1, -3'	-6690475.014	6.271
Homoannus	Id	1, -2	-6690471.914	9.37
	Ie	1, -3	-6690474.148	7.137

To confirm the conclusions on the structure of synthesized compound I, its infrared spectrum was analyzed using a quantum chemical calculation. The IR spectra of the synthesized compounds in KBr were measured on a Perkin Elmer Spectrum IR spectrometer in the range 450-4000 cm⁻¹. To determine the correspondence of the absorption bands in

the IR spectrum of the molecules, the data presented in the literature were used, and the results of quantum chemical calculations were compared. A theoretical calculation of the vibrational spectra of the molecules of the studied substances was carried out on the basis of the 6-311G (2d) method DFT / B3LYP of the Gaussian 98 software package.

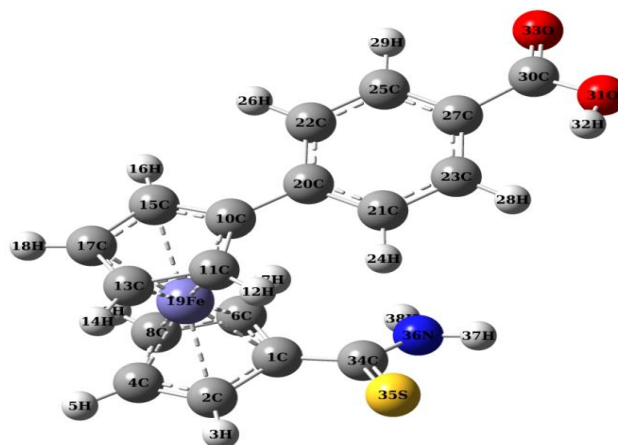


Figure 2. Optimized molecular structure of 1-(4-carboxyphenyl)-1'-N-ferrocenylthioamide

The IR spectrum of 1-(4-carboxyphenyl)-1'-N-ferrocenylthioamide (I) is shown in Figure 3 and table 2 compares the wave numbers of the absorption peaks observed

in the IR spectrum of substance I with the wave numbers of the spectrum maxima absorption calculated by the quantum chemical method for various isomers.

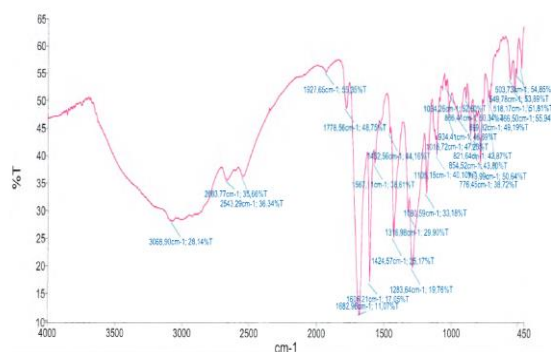


Figure 3. IR spectrum of 1-(4-carboxyphenyl)-1'-N-ferrocenylthioamide (I)

Table 2. The calculated values for different hypothetical isomers and experimentally detected wave numbers of peaks in the IR spectrum of 1-(4-carboxyphenyl)-1'-N-ferrocenylthioamide.

№	Type of oscillation	The wavenumber of the maximum absorption band, cm ⁻¹					
		Calculated					Measured
		Ia	Ib	Ic	Id	Ie	
1.	τ (O-H)(COOH)	455	450	474	448	455	466
2.	δ (CCC) (Cp)	500	506	510	510	509	503
3.	δ (N-H)	541	546	540	589	533	549
4.	δ (1C-34C(S)-36N)	710	705	706	706	703	713
5.	π _s (C-H)(Cp)	776	814	798	810	780	776
6.	ν _s (C=S)	828	840	833	838	842	821
7.	π _s (C-H) (Ar)	892	897	896	908	894	886
8.	ν _s (CCC) (Cp)	940	915	916	-	-	934
9.	τ (C-H)(Ar)	1020	1027	1035	1039	1033	1015
10.	ν _s (C-C) (Cp)	1114	1109	1109	1121	1120	1105
11.	δ (COH)	1211	1209	1208	1204	1210	1203
12.	ν _{as} (C-C-OH)(COOH)	1281	1275	1275	1270	1276	1283
13.	Γ (C-H) (Cp)	1316	1317	1318	1313	1313	1316
14.	Γ (C-H) (Cp)	1424	1425	1425	1439	1440	1424
15.	ν _{as} (CCC) (Ar)	1590	1638	1588	1635	1638	1606
16.	δ (NH ₂)	1677	1674	1674	1681	1674	1682
17.	ν (C=O)	1783	1785	1784	1785	1783	1780
18.	ν _{as} (CH) (Ar)	3078	3178	3177	3182	3179	2800-3700 wide absorption area
19.	ν _s (CH) (Ar)	3229	3230	3230	3226	3229	
20.	ν _s (CH) (Cp)	3285	3283	3283	3279	3285	
21.	ν _{as} (CH) (Cp)	3313	3303	3313	3314	3311	
22.	ν _s (NH)	3494	3486	3490	3477	3492	
23.	ν (OH) (COOH)	3519	3517	3520	3521	3521	
24.	ν _s (NH)	3620	3614	3618	3609	3619	

According to the literature and the calculation data obtained in spectrum I, the scissor bending vibrations of the C-C-C cyclopentadienyl ring in the region of 503 cm⁻¹, the symmetric stretching vibrations of these bonds in the regions of 934 and 1105 cm⁻¹, the absorption region of the pendulum bending vibrations are clearly visible CH bonds in the region of 1316 and 1424 cm⁻¹. Vibrations corresponding to vibrations of the benzoic acid group are observed in the region of 466 cm⁻¹ for (τ (OH) (COOH)), 886 cm⁻¹ for (ν _s (CH) (Ar)), 1015 cm⁻¹ for (τ (CH) (Ar)), 1606 cm⁻¹ for (ν _{as} (CCC) (Ar)) groups. Vibrations corresponding to the thiourea residue are observed in the region of 549 cm⁻¹ for (δ (N-H)), 821 cm⁻¹ for (ν _s (C = S)) and 1682 cm⁻¹ for (δ (NH₂)).

In addition, a comparison of the number of waves of absorption peaks in spectrum (I) with the numbers of vibration waves for its possible isomers proves the correspondence of the obtained compound to the structure of the molecular structure of Ia. Since the absorption regions determined in the experiment for substance (I) are very close to structure Ia than for Ib, Ic, Id, and Ie. The presence of an absorption peak in the region of 934 cm⁻¹ (ν _s (CCC) (Cp)) for substance (I), which is also characteristic of isomer Ia (940 cm⁻¹), indicates the absence of an unsubstituted

cyclopentadienyl ring in the molecule. This means that the thiourea group in the molecule of synthesized substance (I) is attached not to the cyclopentadienyl ring bound to the remainder of benzoic acid, but to the second cyclopentadienyl, i.e. attached heteroannularly at the 1-1-position. If the thiourea residue joined the ferrocene with respect to the benzoic acid group at the 1-2 or 1-3 position, the symmetry of the cyclopentadienyl ring changes significantly, the value of the number of vibration waves for ν _s (CCC) (Cp) is observed in the region below 934 cm⁻¹. In addition, the proximity of the number of waves of absorption peaks in the region of 776 cm⁻¹ (ν _s(C-H)(Cp)), 1316 cm⁻¹ (Γ (C-H) (Cp)), and 1424 cm⁻¹ (Γ (C-H) (Cp)) with the calculated values for the Ia isomer proves the heteroannular, 1,1-disubstituted structure of substance I.

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