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KINETIC RESOLUTION OF N-METHYL-2-PHENYL-PYRROLIDINE BY CYCLOPALLADATION IN THE PRESENCE OF AN OPTICALLY ACTIVE BASE

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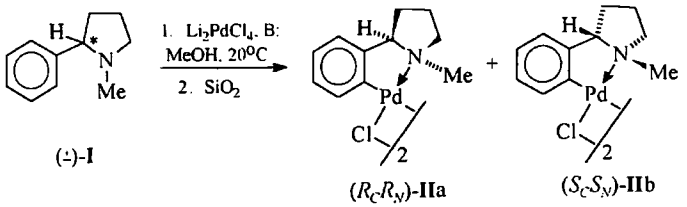
The possibility of the kinetic resolution of the racemic C-chiral ligand in the course of its ortho-palladation in the presence of an optically active base was shown for the first time using a tertiary heterocyclic amine as the ligand. The absolute configuration of the C*-stereocenter in the predominant enantiomer of the dimeric complex was established by the X-ray diffraction of (S)-prolinate derivative.*

Asymmetric activation of C–H bonds seems a highly promising method for the synthesis of optically active metallacycles. However, this approach has remained little studied up to the present, and is only utilized for systems with planar chirality. After the pioneering investigations of Sokolov and coworkers on the asymmetric cyclopalladation of α-ferrocenylalkylamines [1-3] and their ruthenocenyl analogs [4] in the presence of optically active bases (as the external inductor of chirality), a series of publications on the diastereoselective cyclopalladation of optically active ferrocenylimines [5-7] and ferrocenylhydrazones [8,9], containing the C*-stereocenter in the N-substituent as the internal inductor of chirality, appeared only recently.

The present work presents preliminary results of investigation into the asymmetric cyclopalladation of racemic N-methyl-2-phenylpyrrolidine (I) in the presence of optically active bases, as well as the determination of the absolute configuration of the enantiomer formed preferentially on account of kinetic resolution using the method of X-ray diffraction analysis. It should be noted that only one case of kinetic resolution in the course of cyclopalladation of a racemic ligand has been described until now, using the example of the system containing elements of planar and central chirality simultaneously [2].

We previously published [10] the synthesis of the racemic dimeric *ortho*-palladated complex di-μ-chlorobis[2-(1-methylpyrrolidin-2-yl)phenyl-C,N]dipalladium(II) (II) and its optical resolution using (*S*)-prolinate as the auxiliary chiral ligand.

When salts of N-acetyl derivatives of optically active aminoacids were used instead of the traditional sodium acetate as the base in the *ortho*-palladation reaction of the racemic tertiary amine I, we detected the formation of the dimer II in the optically active form (Table 1). Column chromatography was used in all the experiments for the isolation of the dimeric complex II to ensure the absence of impurities, including optically active ones, in the samples obtained.



(±)-I

(R_C-R_N)-IIa

(S_C-S_N)-IIb

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TABLE 1. Kinetic Resolution in the *ortho*-Palladation of the Ligand I

Entry	Reaction conditions			Characteristics of the dimer II	
	I : Pd	T, °C	degree of metallation, %*	$[\alpha]_D$ (c 0.32, $CHCl_3$)	optical purity, % *ee*
	B: = sodium N-acetyl-(*R*)-valinate				
1	1 : 1	20	62	-2.5	1.1
2	1 : 1	20	34	-7.8	3.4
3	2 : 1	20	16	-16.3	7.2
4	1 : 1	0	36	-17.5	7.7
	B: = sodium N-acetyl-(*R*)-leucinate				
5	1 : 1	20	58	0	0
6	2 : 1	20	58	-18.8	8.3
	B: = sodium N-carbobenzyloxy-(*S*)-prolinate				
7	2 : 1	20	51	+3.5	1.5

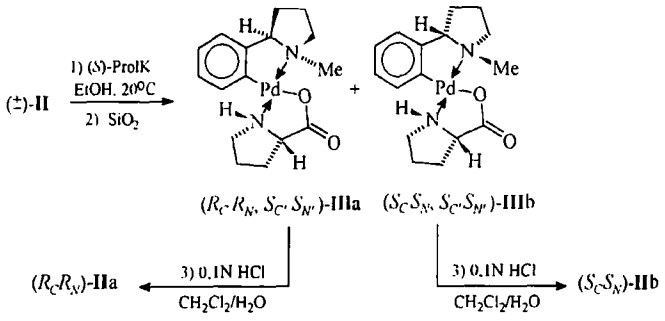
* The yield of the isolated chromatographically pure dimer.

The maximum value of the specific rotation of the dimer II does not exceed -19°, which corresponds with the 8.3% ee enantiomeric purity of the dimer taking into account the specific rotation previously found for the enantiomerically pure dimer – the $[\alpha]_D$ -227° (c 0.32, $CHCl_3$) [10]. Nevertheless, the characteristics presented can be considered completely reliable since the angle observed most frequently exceeds the instrumental error by at least one order of magnitude.

Analysis of the data presented in Table 1 shows that the optical yield of the dimer in the kinetic resolution of the racemic amine I is somewhat higher in the early stages of the process (cf. entries 1 and 2) and increases when the temperature is decreased (cf. entries 2 and 4). When the ratio of I–Pd is changed from 1:1 to 2:1, the effectiveness of the stereoselectivity increases (cf. entries 2 and 3, and entries 5 and 6). This may occur both on account of the delayed process of the C–H bond activation in the case of the route including the *trans*-bis(ligand) intermediate, and as a consequence of the higher possibility of the selection of one of the two substrate enantiomers.

Consideration of the influence of the optically active base structure on the effectiveness of the kinetic resolution is premature at the stage of the preliminary investigation. It can only be noted that when the N-acetyl derivatives of (*R*)-aminoacids (valine and leucine) are used as the base, the (-)-*D*-enantiomer of the dimeric complex II (IIa) is formed at a higher rate than the (+)-*D*-enantiomer (cf. entries 1-6 and 7). The negligible optical purity of the complex obtained by use of the N-carbobenzyloxy-(*S*)-prolinate anion (entry 7) can be explained by the significance of hydrogen bonds with the amide NH group of the base in the conformational stabilization of the transition state in the process of *ortho*-palladation.

The absolute configuration of the (-)-*D*-enantiomer of the dimeric complex II, preferentially formed in the presence of aminoacidate bases of the (*R*)-configuration as stereocontrol agents, was determined by X-ray diffraction analysis of its (*S*)-prolinate derivative IIIa, which was isolated and spectrally characterized previously [10] in the optical resolution of the racemic dimer (±)-II according to the scheme presented below.



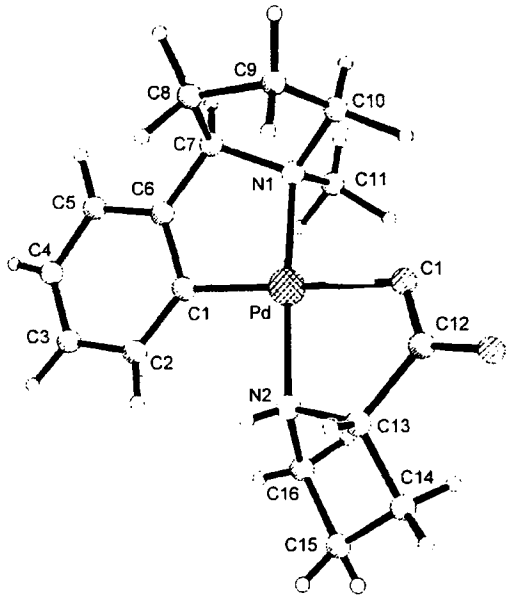


Fig. 1. Molecular structure of the (*S*)-prolinate derivative of *ortho*-palladated N-methyl-2-phenylpyrrolidine IIIa in the projection of the approximately orthogonal coordination plane.

The molecular structure of the adduct IIIa in three projections is presented in Figs. 1-3, and the selected bond lengths and values of bond angles and some torsion angles are presented in Tables 2, 3, and 4 correspondingly.

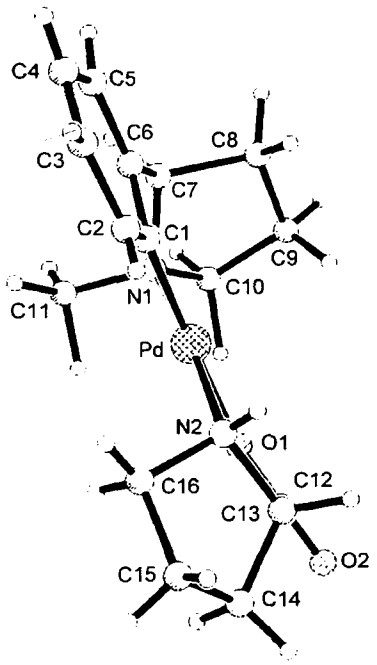
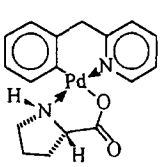


Fig. 2. "Side" projection of the complex ($R_C R_N$,$S_C S_{N'}$)-IIIa molecule in relation to the coordination plane.

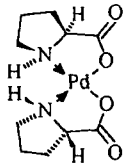
TABLE 2. Selected Bond Lengths

Bond	Length, Å	Bond	Length, Å
Pd–$C_{(1)}$	1.975(4)	$C_{(2)}$–$C_{(3)}$	1.370(6)
Pd–$N_{(2)}$	2.048(3)	$C_{(3)}$–$C_{(4)}$	1.343(7)
Pd–$N_{(1)}$	2.069(3)	$C_{(4)}$–$C_{(5)}$	1.373(7)
Pd–$O_{(1)}$	2.107(3)	$C_{(5)}$–$C_{(6)}$	1.401(7)
$O_{(1)}$–$C_{(12)}$	1.267(5)	$C_{(6)}$–$C_{(7)}$	1.507(6)
$O_{(2)}$–$C_{(12)}$	1.237(5)	$C_{(7)}$–$C_{(8)}$	1.583(7)
$N_{(1)}$–$C_{(10)}$	1.439(6)	$C_{(8)}$–$C_{(9)}$	1.512(7)
$N_{(1)}$–$C_{(11)}$	1.473(6)	$C_{(9)}$–$C_{(10)}$	1.491(7)
$N_{(1)}$–$C_{(7)}$	1.496(6)	$C_{(12)}$–$C_{(13)}$	1.533(5)
$N_{(2)}$–$C_{(16)}$	1.493(4)	$C_{(13)}$–$C_{(14)}$	1.537(5)
$N_{(2)}$–$C_{(13)}$	1.502(5)	$C_{(14)}$–$C_{(15)}$	1.519(5)
$C_{(1)}$–$C_{(2)}$	1.385(6)	$C_{(15)}$–$C_{(16)}$	1.511 (5)
$C_{(1)}$–$C_{(6)}$	1.397(5)		

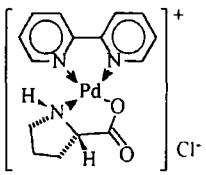
In spite of the wide application of (*S*)-proline (ProlH) in the optical resolution of palladacycles [10-14], only one work on the X-ray analysis of the *ortho*-palladated complex IV, containing the achiral six-membered palladacycle with an additional prolinate ligand, has been published [15]. Structures of two bischelate coordination compounds of palladium(II), namely the bis{(*S*)-prolinate} complex V [16] and the ionic mixed ligand derivative VI, crystallized as the trihydrate, are also known [17].



(S_C,S_N)-**IV**



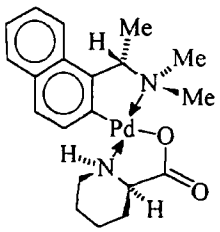
(S_C,S_N, S_i,S_N)-**V**



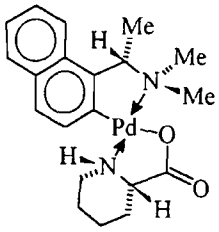
(S_C,S_N)*-**VI**

R.p. 1142

The only example of the structural investigation of an adduct of homochiral cyclopalladated α-arylalkylamine with the cyclic aminoacidate ligand can be mentioned in the work of Wild and coworkers [18] who performed X-ray diffraction analysis of both diastereomeric derivatives, (S_C,R_C,R_N)-VIIa and (S_C,S_C,S_N)-VIIb, isolated in the course of the optical resolution of racemic piperidine-2-carboxylic acid on the N,N-dimethyl-{1-(1-naphthyl)ethyl}aminate palladacycle.



(S_C,R_C,R_N)-**VIIa**



(S_C,S_C,S_N)-**VIIb**

Comparison of the geometric parameters of the palladacycle in the adduct IIIa with those of the closest analogs (S_C,R_C,R_N)-VIIa and (S_C,S_C,S_N)-VIIb, as well as the parameters of the prolinate chelate ring in the complex IIIa with those of the previously described compounds IV-VI shows that they differ insignificantly and are completely regular.

TABLE 3. Bond Angles

Angle	ω, deg	Angle	ω, deg
$C_{(1)}$–Pd–$N_{(2)}$	99.44(14)	$C_{(3)}$–$C_{(4)}$–$C_{(5)}$	119.1(5)
$C_{(1)}$–Pd–$N_{(1)}$	82.4(2)	$C_{(4)}$–$C_{(5)}$–$C_{(6)}$	120.8(5)
$N_{(2)}$–Pd–$N_{(1)}$	176.1(2)	$C_{(1)}$–$C_{(6)}$–$C_{(5)}$	119.9(5)
$C_{(1)}$–Pd–$O_{(1)}$	177.47(14)	$C_{(1)}$–$C_{(6)}$–$C_{(7)}$	116.9(4)
$N_{(2)}$–Pd–$O_{(1)}$	81.86(11)	$C_{(5)}$–$C_{(6)}$–$C_{(7)}$	123.1(5)
$N_{(1)}$–Pd–$O_{(1)}$	96.47(13)	$N_{(1)}$–$C_{(7)}$–$C_{(6)}$	107.1(4)
$C_{(12)}$–$O_{(1)}$–Pd	114.8(2)	$N_{(1)}$–$C_{(7)}$–$C_{(8)}$	101.5(5)
$C_{(10)}$–$N_{(1)}$–$C_{(11)}$	108.4(4)	$C_{(6)}$–$C_{(7)}$–$C_{(8)}$	114.8(5)
$C_{(10)}$–$N_{(1)}$–$C_{(7)}$	106.2(4)	$C_{(9)}$–$C_{(8)}$–$C_{(7)}$	104.0(5)
$C_{(11)}$–$N_{(1)}$–$C_{(7)}$	110.9(5)	$C_{(10)}$–$C_{(9)}$–$C_{(8)}$	107.0(5)
$C_{(10)}$–$N_{(1)}$–Pd	114.6(3)	$N_{(1)}$–$C_{(10)}$–$C_{(9)}$	102.4(4)
$C_{(11)}$–$N_{(1)}$–Pd	107.9(3)	$O_{(2)}$–$C_{(12)}$–$O_{(1)}$	124.5(4)
$C_{(7)}$–$N_{(1)}$–Pd	108.9(3)	$O_{(2)}$–$C_{(12)}$–$C_{(13)}$	117.4(4)
$C_{(16)}$–$N_{(2)}$–$C_{(13)}$	106.1(3)	$O_{(1)}$–$C_{(12)}$–$C_{(13)}$	118.1(4)
$C_{(16)}$–$N_{(2)}$–Pd	115.0(2)	$N_{(2)}$–$C_{(13)}$–$C_{(12)}$	112.7(3)
$C_{(13)}$–$N_{(2)}$–Pd	110.7(2)	$N_{(2)}$–$C_{(13)}$–$C_{(14)}$	106.3(3)
$C_{(2)}$–$C_{(1)}$–$C_{(6)}$	116.9(4)	$C_{(12)}$–$C_{(13)}$–$C_{(14)}$	113.1(3)
$C_{(2)}$–$C_{(1)}$–Pd	129.3(3)	$C_{(15)}$–$C_{(14)}$–$C_{(13)}$	104.1(3)
$C_{(6)}$–$C_{(1)}$–Pd	113.9(3)	$C_{(16)}$–$C_{(15)}$–$C_{(14)}$	102.3(3)
$C_{(3)}$–$C_{(2)}$–$C_{(1)}$	122.0(5)	$N_{(2)}$–$C_{(16)}$–$C_{(15)}$	103.9(3)
$C_{(4)}$–$C_{(3)}$–$C_{(2)}$	121.2(5)		

The Pd–$C_{(1)}$ and Pd–$N_{(1)}$ bond lengths of 1.975 and 2.069 Å correspondingly (Table 2) in the palladacycle of the complex IIIa are in the range presented for the diastereomers (S_C,R_C,$R_{N'}$)-VIIa and (S_C,S_C,$S_{N'}$)-VIIb (1.999-1.937 and 2.078-2.048 Å correspondingly). As should be expected, the Pd-$O_{(1)}$ bond of the chelate ring formed by the prolinate ligand is noticeably longer in the case of the adduct IIIa by comparison with the corresponding parameter in the simple coordination complexes V and VI (2.107 and 1.950-2.021 Å correspondingly) due to the strong *trans*-influence of the Pd–C σ bond. In contrast, this value is in good agreement with the range of values found for structures of other aminoacidate derivatives of the cyclopalladated complexes IV and VIIa,b (2.093-2.148 Å).

TABLE 4. Torsion Angles for Five-Membered Metallacycles and Heterocycles in the Complex IIIa

Fragment	Metallacycles		Pyrrolidine rings	
	angle	ω, deg	angle	ω, deg
ortho-Palladated	Pd–$C_{(1)}$–$C_{(6)}$–$C_{(7)}$	-6.6	$N_{(1)}$–$C_{(7)}$–$C_{(8)}$–$C_{(9)}$	+16.0
	$C_{(1)}$–$C_{(6)}$–$C_{(7)}$–$N_{(1)}$	+27.9	$C_{(7)}$–$C_{(8)}$–$C_{(9)}$–$C_{(10)}$	+9.9
	$C_{(6)}$–$C_{(7)}$–$N_{(1)}$–Pd	-34.7	$C_{(8)}$–$C_{(9)}$–$C_{(10)}$–$N_{(1)}$	-33.2
	$C_{(7)}$–$N_{(1)}$–Pd–$C_{(1)}$	+26.4	$C_{(9)}$–$C_{(10)}$–$N_{(1)}$–$C_{(7)}$	+44.8
	$N_{(1)}$–Pd–$C_{(1)}$–$C_{(6)}$	-11.3	$C_{(10)}$–$N_{(1)}$–$C_{(7)}$–$C_{(8)}$	-37.9
	Mean angle	21.4	Mean angle	28.4
Prolinate	Pd–$O_{(1)}$–$C_{(12)}$–$C_{(13)}$	+9.0	$N_{(2)}$–$C_{(13)}$–$C_{(14)}$–$C_{(15)}$	-16.2
	$O_{(1)}$–$C_{(12)}$–$C_{(13)}$–$N_{(2)}$	+1.1	$C_{(13)}$–$C_{(14)}$–$C_{(15)}$–$C_{(16)}$	+35.4
	$C_{(12)}$–$C_{(13)}$–$N_{(2)}$–Pd	-10.6	$C_{(14)}$–$C_{(15)}$–$C_{(16)}$–$N_{(2)}$	-41.9
	$C_{(13)}$–$N_{(2)}$–Pd–$O_{(1)}$	+11.6	$C_{(15)}$–$C_{(16)}$–$N_{(2)}$–$C_{(13)}$	+32.1
	$N_{(2)}$–Pd–$O_{(1)}$–$C_{(12)}$	-12.0	$C_{(16)}$–$N_{(2)}$–$C_{(13)}$–$C_{(14)}$	-9.7
	Mean angle	8.9	Mean angle	27.1

We established the absolute configuration of the *ortho*-palladated N-methyl-2-phenylpyrrolidine (R_CR_N) both by utilizing the (*S*)-prolinate ligand in the diastereomer IIIa as the reference point, and independently, on the basis of the anomalous scattering of X-rays [the Flack parameter -0.05(4)]. We will note that, on the basis of the comparison of the CD spectra of the dimer (-)-*D*-IIa, isolated from the diastereomer IIIa, with the spectra of analogous derivatives of acyclic benzylamines, the opposite (S_CS_N)-stereochemistry of the palladacycle was assumed previously [10] in these genetically connected complexes. Therefore, the main point of the analysis of the structural features of the molecule IIIa was the clarification of possible additional sources of chirality.

One of such elements of chirality may be the tetrahedral distortion of the coordination sphere in the structures of complexes with benzylaminate palladacycles, reaching 20° due to the steric requirements of the palladacycle [19] or the bulky additional ligand bounded to it [20, 21].

In the complex (R_CR_N,S_C'S_N')-IIIa, the Pd(II) atom is situated in a square-planar coordination environment with insignificant distortion. The sum of the angles at the metal center comprises 360.17°, and the donor atoms only come out of the mean coordination plane $\{PdC_{(1)}O_{(1)}N_{(1)}N_{(2)}\}$ by ±0.05Å. The tetrahedral character of the distortion can be seen from the directions of displacement of the atoms connected to palladium: two pairs of *trans*-disposed donor atoms come out of the mean coordination plane at the opposite sides, namely the $C_{(1)}$ and $O_{(1)}$ atoms "above," and both nitrogen atoms "below" (Fig. 2). However, the value of this tetrahedral distortion is low with the angle 4.4° between the $\{C_{(1)}PdN_{(1)}\}$ and $\{O_{(1)}PdN_{(2)}\}$ planes, pertaining to two chelate rings, which only insignificantly exceeds the limits of the range of values of 1.2-2.7° characterizing the related complexes IV-VII. It can be seen that such a weak tetrahedral distortion of the complex (R_CR_N,S_C'S_N')-IIIa structure cannot make an appreciable contribution to its chiral-optical properties.

The asymmetry of the molecule of the *ortho*-palladated heterocyclic ligand (R_CR_N,S_C'S_N')-IIIa may differ from that of derivatives of acyclic analogs due to conformational effects. This molecule contains four aliphatic five-membered rings: the palladacycle and the prolinate chelate ring, as well as two pyrrolidine rings.

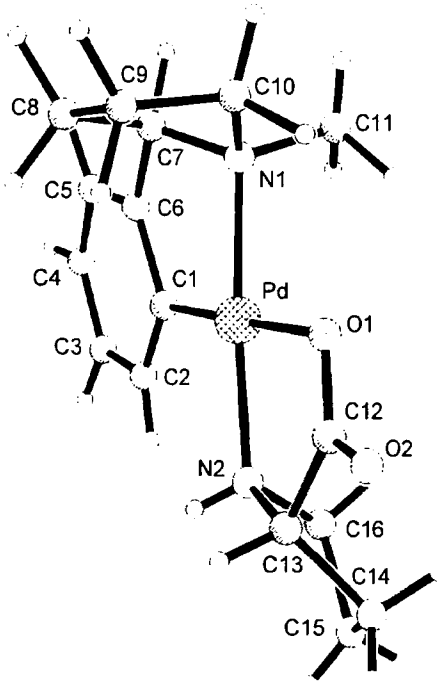


Fig. 3. The chiral conformation of the pyrrolidine ring of the (*S*)-prolinate ligand in the adduct (R_CR_N,S_C'S_N')-IIIa.

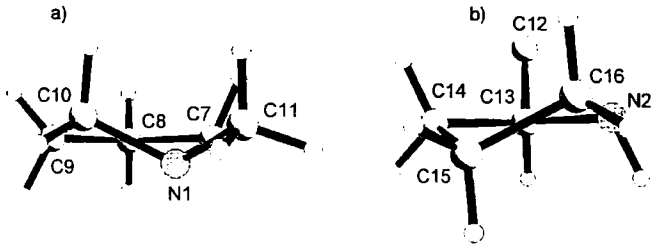


Fig. 4. The opposite directions of the torsion of the pyrrolidine rings in the *ortho*-palladated portion of the (R_CR_N)-configuration (the δ-conformation; a), and the ($S_CS_{N'}$)-prolinate ligand (the λ-conformation; b).

Comparison of the intrachelate torsion angles for the five-membered palladacycle in the adduct (R_CR_N,$S_CS_{N'}$)-IIIa (Table 4) and in the two diastereomers of the N,N-dimethyl-{1-(1-naphthyl)ethyl}amine analog VIIa,b shows that they differ insignificantly. In all three complexes, the palladacycle has the conformation of the distorted envelope with approximately the same degree of torsion: the mean value of the intrachelate torsion angle* comprises 21.4 and 21.8-24.7°, for the complexes IIIa and VIIa,b, correspondingly.

The signs of the intrachelate torsion angles are opposite for all three complexes, which conforms with the opposite absolute configuration of the C*-stereocenter in them. That indicates the same relative stereochemistry of the palladacycles: in the complex (R_CR_N,$S_CS_{N'}$)-IIIa, it has the δ(R_C)-conformation which is opposite to the λ(S_C)-conformation in the case of the analogs (S_C,$R_CR_{N'}$)-VIIa and (S_C,$S_CS_{N'}$)-VIIb.

The chelate ring formed by the prolinate ligand in the complex (R_CR_N,$S_CS_{N'}$)-IIIa investigated by us has the form of the strongly flattened envelope (cf. Fig. 2 and Table 4) with the mean intrachelate torsion angle of 8.9°. The conformation of the metallacycle formed by the (*S*)-prolinate in the previously described complexes IV-VI changes within very wide limits according to the degree and direction of the torsion, with the range of 4.3-21.7° for the mean intrachelate angle. That indicates its high conformational flexibility.

Both pyrrolidine rings in the complex (R_CR_N,$S_CS_{N'}$)-IIIa, both in the *ortho*-palladated ligand and in the prolinate ligand, have the conformation of the twisted envelope with a higher degree of nonplanarity by comparison with the metallacycles: the mean intracyclic torsion angles are 27.1 and 28.4° correspondingly. The torsion of the pyrrolidine heterocycles has a chiral character, which is completely evident from Fig. 3.

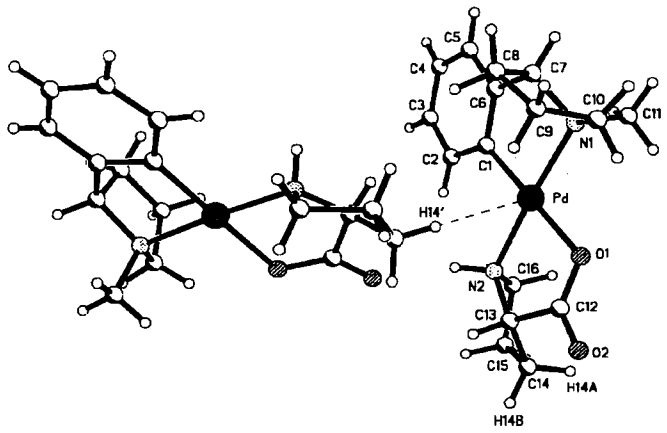


Fig. 5. Association of the complex (R_CR_N,$S_CS_{N'}$)-IIIa molecules in the crystal on account of weak agostic interactions C–H···Pd.

* Obtained by averaging the absolute values of the intrachelate torsion angles.

TABLE 5. Crystal Data and Refinement Parameters

Characteristic	Value
Empirical formula	$C_{16}H_{22}N_2O_2Pd$
Molecular weight	380.76
Temperature, K	293
Color, habit	Colorless prisms
Crystal size, mm	0.54 × 0.36 ×0.38
Syngony	Orthorhombic
Space group	$P2_12_12_1$
Unit cell dimensions:	
a, Å	8.441(3)
b, Å	10.844(3)
c, Å	17.407(4)
α, deg	90
β, deg	90
γ, deg	90
V, Å^3	1593.3
Z	4
ρ, g/cm^{-1}	1.587
μ_{Mo}, mm^{-1}	1.170
F(000)	776
Radiation (λ, Å)	MoKα (0.71073
θ range, deg	2.21-29.95
Range of indexes of reflections	$0 \le h \le 11.0 \le k \le 15.0 \le l \le 24$
Number of measured reflections	1925
Number of independent reflections	1925 [*R*(int) = 0.0000]
Method of solution	Direct, SHELXS-86
Method of refinement	Full-matrix MLS by F^2, SHELXL-93
Treatment of hydrogen atoms	All hydrogen atoms are placed in the calculated positions (d_{C-H} = 0.93 Å for aromatic hydrogen atoms; d_{C-H} = 0.97 Å for the remaining hydrogen atoms) and specified by the use of rider model.
Number of reflections/number of variables	1925 / 192
GOOF	0.855
R-factors [$I > 2\sigma(I)$], R_1 and wR_2	0.0226 and 0.0453
R-factors (all *I*), R_1 and wR_2	0.0226 and 0.0453
Flack parameter	-0.05(4)
Extinction coefficient	0.0119(4)
Max/min of electron density, e × Å^{-3}	0.402 and -0.301

The pyrrolidine moiety of the *ortho*-palladated (R_CR_N)-ligand in the crystal has the δ-conformation (Fig. 4a) with the $C_{(15)}$ and $C_{(16)}$ atoms orientated at different sides from the plane of three atoms of the heterocycle $\{N_{(2)}C_{(13)}C_{(14)}\}$ at distances of +0.4112 and -0.2411 Å correspondingly. In contrast, the pyrrolidine ring of the (S_CS_N)-prolinate ligand takes up the opposite λ-conformation in conformity with the change in the absolute configuration of the C*-stereocenter (Fig. 4b); the $N_{(1)}$ and $C_{(10)}$ atoms thereby come out of the plane $\{C_{(7)}C_{(8)}C_{(9)}\}$ on different sides at distances of +0.4031 and -0.2449 Å correspondingly. The comparison of the geometric parameters of the pyrrolidine ring in the (S_CS_N)-prolinate complexes IV-VII shows the high conformational flexibility of this five-membered heterocycle: the mean intracyclic angle varies in the range 14.7-26.8°, and the direction of the ring torsion also changes thereby.

It is possible that the same (positive) sign of the specific rotation of both diastereomeric prolinate derivatives (R_CR_N,S_CS_N)-IIIa and (S_CS_N,S_CS_N)-IIIb, with the corresponding $[\alpha]_D$ +72 and 204° [10], may be explained by the high contribution of the chiral conformation of the pyrrolidine ring to the optical activity.

An additional element of the chirality in the structure of the adduct (R_CR_N,S_CS_N)-IIIa is the specific helical disposition of the two pyrrolidine rings in relation to the mean coordination plane (Fig. 3). In the consideration of the structure of the complex along the diagonal of the angle $C_{(1)}PdN_{(2)}$, the pyrrolidine rings of the *ortho*-palladated and prolinate ligands are found to be orientated to the left behind the coordination plane upward, and to the right in front of it downwards, thereby forming two blades of a righthand propeller.

Packing of the complex (R_CR_N,$S_CS_{N'}$)-IIIa molecules in the crystal also merits comment. The neutral molecules form infinite chains along the 2_1 axis on account of the unusual variety of hydrogen bond in which the palladium atom and one of the β-hydrogen atoms of the prolinate ligand of a neighboring molecule participate (Fig. 5). The distance $H_{(14')}$···Pd is thereby shortened to 2.790 Å by comparison with the sum of the van der Waals radii of these atoms at 3.1 Å [22], and the angle at the hydrogen atom comprises 157.8°. These parameters lead one to assume the attractive character of the $H_{(14')}$···Pd interaction. We first observed a similar intermolecular agostic C–H···Pd interaction in the structure of the ionic adduct of *ortho*-palladated secondary benzylamine with stilbenediamine [23, 24].

Summarizing the results of the X-ray diffraction analysis of the prolinate complex (R_CR_N,$S_CS_{N'}$)-IIIa, it can be concluded that the inclusion of the benzylaminate nitrogen atom in the five-membered pyrrolidine ring does not introduce principal changes in the stereochemistry of the palladacycle by comparison with acyclic analogs. The chiral conformation of the pyrrolidine ring may introduce a marked contribution to the chiral-optical properties of *ortho*-palladated derivatives of saturated nitrogen heterocycles. However, the prediction of the sign of this contribution may not be correct owing to the high conformational flexibility of the pyrrolidine ring.

EXPERIMENTAL

The specific rotation at the D-line of Na is registered on the A1-EPO VNIIEKIProdmash automatic polarimeter. The melting temperature is measured using EM-MGU-49 melting point indicator in a sealed capillary.

The dichloromethane and chloroform are passed through a column with neutral Al_2O_3 (Chemapol L 40/250), and are further distilled in a stream of argon. The methanol is dried by refluxing over magnesium methoxide and subsequent distillation. The benzene is dried with $CaCl_2$, refluxed and distilled over Na. The acetone of high purity is used without additional purification. The monitoring of the course of reactions is accomplished using TLC on Silufol.

The initial lithium tetrachloropalladate is synthesized by a described method [25] and then carefully dried in vacuo at 3 mm Hg at room temperature over P_2O_5. The N-acetyl-(*R*)-leucine is obtained by the acylation of (*R*)-leucine under conditions previously described [26] for the (*S*)-enantiomer in yield 45%; $[\alpha]_D$ +23.9° (c 4, MeOH). The published data for N-acetyl-(*S*)-leucine are as follows: $[\alpha]_D$ -23.9° (c 4, MeOH) [26]. The N-acetyl-(*R*)-valine is recrystallized from methanol, and the N-carbobenzyloxy-(*S*)-proline is used without additional purification.

The N-methyl-2-phenylpyrrolidine (I) is obtained by a known method [27]; bp 87-88°C (8 mm Hg); lit. data: bp 106°C (20 mm of Hg).

Asymmetric Synthesis of Di-μ-chloro-bis-[2-(1-methylpyrrolidin-2-yl)phenyl-C,N]dipalladium(II) (II). The solution of sodium N-acetyl-(*R*)-leucinate is prepared *in situ* by the treatment of N-acetyl-(*R*)-leucine (0.066 g, 0.38 mmol) with the equimolar amount of NaOH (0.015 g, 0.38 mmol) in methanol (4 ml). To the prepared solution, the solution of Li_2PdCl_4 in MeOH (3 ml) and then the solution of the amine I (0.061 g, 0.38 mmol) in MeOH (3 ml) are added sequentially. The reaction mixture is stirred for 15 min at ~20°C, and the precipitated residue is filtered off and washed with methanol prior to extraction of the dimer II from the residue with dichloromethane. The organic extract is concentrated to the volume of 2-3 ml in vacuo and purified chromatographically utilizing a "dry column" [28, 29] (Silpearl, h = 2 cm, d = 2 cm; eluent benzene–acetone, 50:1). The chromatographically pure dimer is isolated as an amorphous pale-yellow powder. Yield 52% (0.060 g, 0.20 mmol). The methanolic mother liquor from the reaction mixture is concentrated to dryness; it is dissolved in dichloromethane (5 ml), and impurities are extracted with water (3 × 3 ml) prior to the drying with anhydrous Na_2SO_4 and chromatographic purification on a "dry column" (Silpearl, h = 4 cm, d = 2 cm; eluent benzene–acetone of increasing polarity, 100:1 to 20:1). The additional amount of the dimer (0.007 g) is thereby isolated. The total yield of the dimeric complex II 58% (0.067 g, 0.11 mmol). R_f 0.63 (Silufol, benzene–acetone, 10:1). R_f 0.55 (Silufol, benzene–acetone, 20:1). R_f 0.14 (Silufol, ether–hexane, 1:1); mp 180-181°C (with decomp.). Lit. mp 179-180°C (with decomp.) [10].

The identity of the complex II obtained with that described previously [10] was confirmed both chromatographically (TLC by comparison with the authentic sample in the systems indicated above), and on the basis of the ^{1}H NMR spectral characteristics of the mononuclear adduct produced *in situ* by treatment of the dimer with a small excess of D_5-pyridine.

The remaining experiments on the asymmetric *ortho*-palladated amine I were carried out analogously; the results are presented in Table 1.

X-ray Structural Studies of the Complex IIIa. The main characteristics of the X-ray diffraction experiment are presented in Table 5. The experimental reflections were obtained on the Enraf–Nonius CAD-4 diffractometer with MoKα radiation. Corrections for Lorentz and polarization factors were applied for them. The correction for absorption of X-rays by the crystal was not taken into account. The structure was solved by direct methods and refined by the method of anisotropic full-matrix least squares analysis for F^2. The hydrogen atoms were refined by the rider model with temperature parameters exceeding, by a factor of 1.5, those of the bounded atoms. The absolute configuration was determined by the method of anomalous scattering according to the Flack parameter, comprising -0.05(4). All calculations were conducted using the SHELXS-86 [30] and SHELXL-93 [31] programs.

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