

Research Article

Pt(II) and Pd(II) Complexes with β -Alanine

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A sequence of stages in the syntheses of isomeric bisamino acid complexes of Pt(II) with β -aminopropionic acid (β -alanine = β -AlaH) has been studied by the ¹⁹⁵Pt NMR spectroscopy. The techniques have been developed of the synthesis of the *cis*- and *trans*-bischelates of Pt(II) and Pd(II) with β -alanine as well as of the halide complexes of *trans*-[M(β -AlaH)₂Cl₂] (M = Pt, Pd) and *trans*-K₂[Pt(β -Ala)₂I₂] types. The NMR spectroscopy and IR spectroscopy (in the nuclei of ¹⁹⁵Pt, ¹³C, ¹H) and X-ray diffraction analysis have been used to examine the structures of the synthesized compounds.

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1. INTRODUCTION

The neoplastic activity of some Pt(II) complexes was discovered in 1971 [1]. It has given an impulse to the growth of platinum metal complexation. The study of the Pt(II) and Pd(II) complexes with amino acids is very promising due to both of their biological activity and their use in the solution of the fundamental problems in coordination chemistry of planar complexes with multifunctional ligands. The Pt(II) and Pd(II) complexes with α -alanine (NH₂CH(CH₃)COOH) are widely described in the literature [2–8].

Less attention has been paid to the Pt(II) complexes with the simplest β -amino acid (β -alanine, β -AlaH–NH₂(CH₂)₂COOH). The syntheses of two bisaminoacid complexes are described in [9]: those of *trans*-[Pt(β -Ala)₂] where β -alanine is a bidentate ligand (coordinated via the NH₂ and OCO groups) and of *trans*-[Pt(β -AlaH)₂Cl₂] where β -alanine is a monodentate ligand (coordinated via the NH₂ group). The *trans*-configuration of these complexes has been proved by chemical methods. No physical methods have been applied to verify their structures.

The monoaminoacid complex K[Pt(NO₂)₂(β -Ala)] with the bidentate β -alanine as well as the bisaminoacid complexes [Pt(NO₂)₂(β -AlaH)₂] and K₂[Pt(NO₂)₂(β -Ala)₂] with the monodentate β -alanine were described in [10]. On the basis of the Kurnakov reaction (thiourea test), it was

concluded [10] that the bisaminoacid complexes of Pt(II) appear to have the *trans*-configuration. The Cambridge crystallographic database only contains some information about one Pt(II) complex with β -AlaH, [Pt(β -Ala)(C₂H₄)Cl], where β -Ala has a bidentate coordination to the Pt atom [11]. So far there has been no evidence of β -AlaH bisaminoacid complexes of Pt(II) with a *cis*-arrangement of ligands. To the authors knowledge the Pd(II) complexes with β -AlaH have never been investigated either.

In this work, the ¹⁹⁵Pt NMR spectroscopy has been used to study the successive stages of the synthesis of bisaminoacid Pt(II) complexes with β -alanine, which can exist in *trans*- and *cis*-configurations. On the basis of the data obtained, we have developed the methods of synthesizing different Pt(II) and Pd(II) bisaminoacid complexes with β -alanine. The complexes in question have been characterized by ¹H, ¹³C NMR, IR spectroscopy, and X-ray diffraction analysis.

2. EXPERIMENTAL

2.1. Syntheses of the *trans*-[Pt(β -AlaH)₂Cl₂] and *trans*-[Pt(β -Ala)₂] complexes

The *trans*-[Pt(β -AlaH)₂Cl₂] and *trans*-[Pt(β -Ala)₂] complexes were synthesized using the techniques suggested in [9], which were slightly modified for the purpose (see Section 3).

2.2. Synthesis of the *trans*-[Pd(β -AlaH)₂Cl₂] complex

0.887 g (5 mmol) of PdCl₂ and 0.585 g (10 mmol) of NaCl were dissolved in 20 mL of water and heated in the water bath until the dilution of PdCl₂. A solution containing 1.78 g (20 mmol) of β -AlaH and 0.800 g (20 mmol) of NaOH in 20 mL of H₂O was added to the solution of K₂[PdCl₄]. After cooling the solution as low as 0°C, 10 mL of concentrated HCl was added to the reaction mixture. The orange precipitate fell out, which was filtered off in an hour, washed with cold water, and dried at room temperature. The yield was up to 85%.

Anal. found (%); C 19.7, H 3.93, N 8.02, Cl 19.5, Pd 29.5. Calcd. for C₆H₁₄N₂O₄Cl₂Pd (%): C 20.3, H 3.94, N 7.88, Cl 20.0, Pd 29.9.

2.3. Synthesis of the *trans*-[Pd(β -Ala)₂] complex

1.0 g of the *trans*-[Pd(β -AlaH)₂Cl₂] was dissolved in 10 mL of water then the reaction mixture was treated with 1 M of NaOH till it became neutral to phenolphthaleine. A light yellow precipitate fell out, which was filtered off and washed with cold water. At first it was dried at room temperature and then at 110°C. The yield was up to 76%.

Anal. found (%); C 25.5, H 4.17, N 9.88, Pd 37.9. Calcd. for C₆H₁₂N₂O₄Pd (%): C 25.5, H 4.25, N 9.92, Pd 37.7.

2.4. Synthesis of the *cis*-[Pd(β -Ala)₂] complex

0.5 g of the *trans*-[Pd(β -Ala)₂] was dissolved in 20 mL of water. The reaction mixture was heated with stirring at 80°C for 3 hours. After cooling the reaction mixture as low as 0°C, a small amount of the starting *trans*-bischelate was filtered off. Then the *cis*-[Pd(β -Ala)₂] was settled with acetone from the filtrate solution (water : acetone ~ 1 : 4) and was filtered off. The solid *cis*-[Pd(β -Ala)₂] was dried at room temperature at first and then at 110°C. The yield was up to 60%.

Anal. found (%); C 25.0; H 4.30; N 10.0; Calcd. for C₆H₁₂N₂O₄Pd (%): C 25.5; H 4.25; N 9.92.

2.5. Synthesis of the *cis*-[Pt(β -Ala)₂] complex

3.32 g (20 mmol) of KI in 25 mL of water was added to 2.08 g (5 mmol) of K₂[PtCl₄] in 25 mL of water. The reaction mixture was heated in the water bath for 10 minutes. A solution of β -AlaH (0.89 g, 10 mmol) in water (25 mL) was added to the reaction mixture, which was heated in the water bath for 2 hours. While heating the reaction mixture, 10 mL of 0.5 M of KOH was added by small portions. Then a small amount of black precipitate was filtered off. The solution of AgNO₃ (3.40 g, 20 mmol) in water (25 mL) was added to the orange solution of the filtrate obtained, and the mixture was heated for ~5 minutes. The coagulated AgI precipitate was filtered off. The reaction product was precipitated with acetone (~100 mL) from the filtrate (V ~50 mL). The yield was up to 20%.

Anal. found (%): Pt 53.1, N 7.65; Calcd. for C₆H₁₂N₂O₄Pt (%): Pt 52.6, N 7.55.

2.6. Measurements

NMR spectra were recorded using a Bruker DPX-250 spectrometer at the frequencies of 250 (¹H), 62.9 (¹³C), and 53.6 (¹⁹⁵Pt) MHz. Two solvents, D₂O and acetone-d₆, were used for the ¹H NMR spectrum: (a) in the D₂O solution, the chemical shifts were determined with reference to the signal of the CH₃-group protons of the DMSO, which was added as an internal standard (δ = 2.660 ppm); (b) in the acetone-d₆ solution, the chemical shifts were determined with reference to the central signal of the acetone residual protons (δ = 2.070 ppm). For the ¹³C NMR spectrum the same solvents, D₂O and acetone-d₆, were used: (a) in the D₂O solution the chemical shifts were determined with reference to the ¹³C signal of the DMSO, which was added as an internal standard (δ = 40.2 ppm); (b) in the acetone-d₆ solution the chemical shifts were determined with reference to the signal of the methyl carbon atom of acetone-d₆ (δ = 29.2 ppm). The chemical shift of the ¹⁹⁵Pt NMR signals was recorded with regard to the external standard, that is, 1 M of the Na₂[PtCl₆] water solution. All measurements were performed at room temperature. The ¹⁹⁵Pt and ¹³C NMR spectra were recorded using proton decoupling.

The IR spectra of crystalline samples packed in the KBr pellets were measured using a Bruker Vector-22 one-beam FT spectrophotometer.

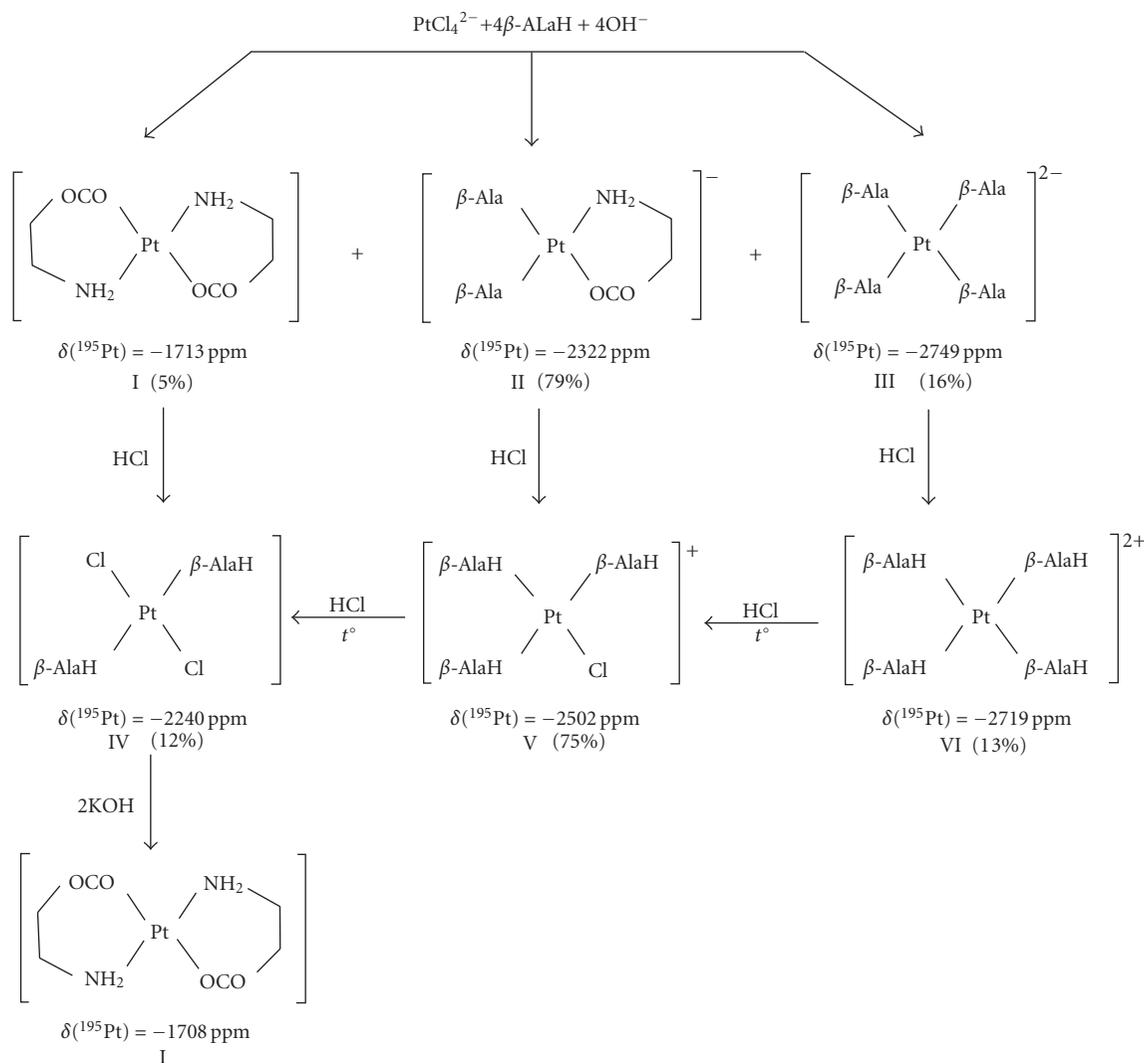
X-ray diffraction analysis. Single-crystal data were collected on a SMART APEX CCD (Bruker AXS) diffractometer (Mo K α , λ = 0.71073 Å, T = 298 K, an absorption correction applied using the Bruker SADABS program, version 2.10). The structures were solved by the direct methods and refined by the full-matrix least squares in an anisotropic approximation for all nonhydrogen atoms. The H atoms were located in difference electron density syntheses and refined together with nonhydrogen atoms in an isotropic approximation. All calculations on the structure solution and refinement were carried out with the Bruker Shelxtl Version 6.14 software.

Trans-[Pd(β -Ala)₂]

C₆H₁₂N₂O₄Pd, M = 282.58, monoclinic crystals, space group $P2_1/n$, a = 5.750(1) Å, b = 8.910(2) Å, c = 9.020(2) Å, β = 104.692(3)°, V = 447.0(2) Å³; Z = 2, ρ_{calc} = 2.100 g·cm⁻³, μ = 2.061 mm⁻¹, 3281 reflections collected ($3.27 < \theta < 23.28^\circ$, R_{int} = 0.0242), including 639 reflections with $I > 2\sigma(I)$, 86 refined parameters, R_1 = 0.0156, wR_2 = 0.0634.

Trans-[Pt(β -Ala)₂]

C₆H₁₂N₂O₄Pt, M = 371.26, monoclinic crystals, space group $P2_1/c$, a = 9.197(4) Å, b = 11.080(5) Å, c = 8.656(4) Å, β = 98.474(6)°, V = 872.4(7) Å³; Z = 4, ρ_{calc} = 2.827 g·cm⁻³, μ = 160.7 cm⁻¹, 6471 reflections collected ($3.53 < \theta < 23.33^\circ$, R_{int} = 0.0388), including 1253 reflections with $I > 2\sigma(I)$, 134 refined parameters, R_1 = 0.0290, wR_2 = 0.0618.

SCHEME 1: Sequence of reactions of $\text{K}_2[\text{PtCl}_4]$ with β -alanine.*Cis*- $[\text{Pt}(\beta\text{-Ala})_2]$

$\text{C}_6\text{H}_{12}\text{N}_2\text{O}_4\text{Pt}$, $M = 371.26$, monoclinic crystals, space group $P2_1/c$, $a = 17.673(3) \text{ \AA}$, $b = 10.232(3) \text{ \AA}$, $c = 10.457(2) \text{ \AA}$, $\beta = 100.043(4)^\circ$, $V = 1862.0(6) \text{ \AA}^3$; $Z = 8$, $\rho_{\text{calc}} = 2.649 \text{ g}\cdot\text{cm}^{-3}$, $\mu = 150.6 \text{ cm}^{-1}$, 6570 reflections collected ($2.90 < \theta < 23.33^\circ$, $R_{\text{int}} = 0.0673$), including 2608 reflections with $I > 2\sigma(I)$, 258 refined parameters, $R_1 = 0.0381$, $wR_2 = 0.0824$.

Trans- $\text{K}_2[\text{Pt}(\beta\text{-Ala})_2] \cdot 2\text{H}_2\text{O}$

$\text{C}_6\text{H}_{16}\text{I}_2\text{K}_2\text{N}_2\text{O}_6\text{Pt}$, $M = 739.30$, monoclinic crystals, space group $P2_1/c$; $a = 5.0414(7) \text{ \AA}$, $b = 24.174(3) \text{ \AA}$, $c = 7.0414(10) \text{ \AA}$, $\beta = 94.045(2)^\circ$, $V = 856.0(2) \text{ \AA}^3$, $Z = 2$, $\rho_{\text{calc}} = 2.868 \text{ g}\cdot\text{cm}^{-3}$, $\mu = 123.1 \text{ cm}^{-1}$, 6375 reflections collected ($1.68 < \theta < 23.29^\circ$, $R_{\text{int}} = 0.0318$), including 1231 reflections with $I > 2\sigma(I)$, 121 refined parameters, $R_1 = 0.0203$, $wR_2 = 0.0475$.

3. RESULTS AND DISCUSSION

3.1. Synthesis of the Pt(II) trans-isomers (Scheme 1)

The solutions of β -AlaH neutralized with an alkali and $\text{K}_2[\text{PtCl}_4]$ were used as the reagents for the synthesis of *trans*-isomers. The molar ratio of the reagents $\text{K}_2[\text{PtCl}_4] : \beta\text{-AlaH} : \text{KOH}$ was as follows 1 : 4.5 : 2. The structures of complexes were detected by the ^{195}Pt NMR spectroscopy at each stage of the synthesis.

According to the data of [9], the first stage of the synthesis is heating of the reaction mixture for 5 hours. We have shown that after heating the aqueous solution of $\text{K}_2[\text{PtCl}_4]$ with the neutralized β -AlaH for 2 hours, the reaction mixture does not contain the starting reagents. Instead, it contains three forms (I, II, and III) of the Pt(II) complexes (Scheme 1), complex II being predominant (~80%). The signal assignment in the ^{195}Pt NMR spectra was carried out using the data of [12].

The second stage comprises the interaction of complexes with HCl. Just after the addition of HCl to the reaction mixture, it is detected that the solution contains complexes IV, V, and VI, complex V prevailing (~75%).

Complex IV is formed from complex I as a result of the ring opening and the insertion of Cl⁻ ions at the site of cleavage of the Pt–OCO bond. Complex V is formed from complex II via the ring opening and the insertion of the Cl⁻ ion. Complex VI is formed from complex III via the protonation of the β-alaninate ions of complex III. The subsequent heating of the reaction mixture in the water bath for ~20 minutes only results in one complex (complex IV) in the solution. During this period, complex VI converts into complex V, while complex V transforms into the *trans*-dichloride IV due to the replacement of β-AlaH with the Cl⁻ ion on the coordinate Cl–Pt–β-AlaH. The given replacement takes place in accordance with the kinetic effect of the *trans*-influence of ligands. That is, the *trans*-effect of Cl exceeds that of the NH₂, the group of β-alanine [13].

At the next stage, the yellow precipitate of the *trans*-[Pt(β-AlaH)₂Cl₂](IV) gradually settles from the solution. The titration of complex IV with the KOH solution leads to the formation of yellow K₂[Pt(β-Ala)₂Cl₂] solution, which is then heated to form a white precipitate of *trans*-[Pt(β-Ala)₂](I).

3.2. Synthesis of *trans*-isomers of the Pd(II) complexes

The problems of isolation of the individual geometrical isomers of the Pd(II) bisaminoacid complexes with α-amino acids are related to the *trans*-*cis* isomerization processes. For the first time we described these processes for Pd(II) bischelates with glycine and α-alanine in [5, 14].

The decrease of temperature from 100°C to 0°C at the appropriate stages of the synthesis rules out the isomerization processes and allows us to use the same approaches to the synthesis of the Pd(II) complexes as is the case with the Pt(II) complexes.

The interaction of Na₂[PdCl₄] with the neutralized β-AlaH in an aqueous solution is likely to result in the formation of complexes similar to the complexes I, II, and III (Scheme 1). The treatment with HCl_{conc} leads to the *trans*-[Pd(β-AlaH)₂Cl₂] as the only product. The formation of a *trans*-isomer as the only product is possible due to the kinetic effect of the *trans*-influence of ligands as is the case with the Pt complexes [13].

The titration of the *trans*-[Pd(β-AlaH)₂Cl₂] with an alkaline solution leads to the ring closure and the formation of the *trans*-[Pd(β-Ala)₂]. The ring closure reaction was conducted at room temperature because the *trans*-bischelate product precipitated immediately. As the *cis*-bischelate readily dissolves in water, it cannot be present in the solid precipitate of the *trans*-[Pd(β-Ala)₂] as an impurity.

The treatment of the *trans*-[Pd(β-Ala)₂] with HCl at ~0°C leads to the opening of amino acid cycles and the formation of the *trans*-[Pd(β-AlaH)₂Cl₂].

3.3. Synthesis of the *cis*-[Pd(β-Ala)₂] complex

Due to its high solubility in water, the *cis*-[Pd(β-Ala)₂] complex can hardly be isolated as a solid. That is why the procedures that we have developed for the synthesis of the Pd(II) *cis*-bischelates with valine [15] are not applicable for the preparation of the solid *cis*-[Pd(β-Ala)₂] phase. The kinetic and thermodynamic data for the *trans*-*cis* isomerization of the Pd(II) bischelates with valine are reported in [15]. It can be supposed that the equilibrium and rate constants of the isomerization reaction are almost similar for the bischelates where amino acids are bonded to Pd(II) via the NH₂ or OCO groups. Thus for the synthesis of the *cis*-[Pd(β-Ala)₂], we have used the kinetic and thermodynamic data of [15].

The *trans*-[Pd(β-Ala)₂] was heated with water at 80°C until the starting precipitate was completely diluted. The *trans*-isomer isomerized, and the *cis*-isomer stayed in solution. At 80°C the equilibrium constant of the *trans*-*cis* process was lower than at low temperatures because the reaction is exothermal (see [15]). So the reaction mixture was abruptly cooled to ~0°C in order to increase the concentration of the *cis*-bischelate. Moreover after cooling, the starting *trans*-bischelate, which did not isomerize, precipitated and was filtered off. The solid *cis*-[Pd(β-Ala)₂] was settled with acetone from the aqueous filtrate solution.

The treatment of the *cis*-[Pd(β-Ala)₂] with HCl did not allow us to form the *cis*-[Pd(β-AlaH)₂Cl₂] as is the case with the *trans*-isomers. Even a highly diluted solution of HCl resulted not only in the opening of the amino acid cycles, but also in completing the substitution of the amino acid ligands and the formation of PdCl₄²⁻. Similar processes were observed for the Pd(II) complexes with valine [15] and for the Pd(II) complexes with aminobutyric acid [16].

3.4. Synthesis of the *cis*-isomers of the Pt(II) complexes (Scheme 2)

For the synthesis of the *cis*-bischelate, we have used K₂[PtI₄], which is formed by the reaction of K₂[PtCl₄] with KI.

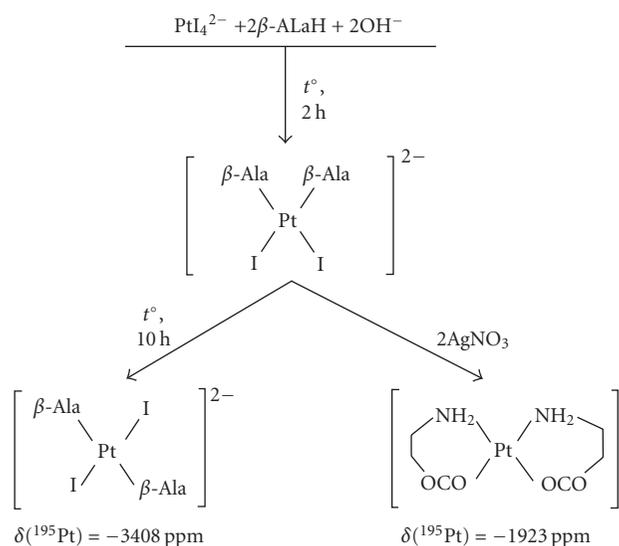
We supposed that the heating of K₂[PtI₄] with β-AlaH at pH ~6-7 (pH was kept at this level by adding KOH) led to the formation of *cis*-K₂[Pt(β-Ala)₂I₂]. The formation of the *cis*-isomer was expected to be in agreement with the kinetic effect of the *trans*-influence (TI) of the ligands (TI (I⁻) ≫ TI(NH₂)).

Further heating of the *cis*-K₂[Pt(β-Ala)₂I₂] does not lead to the ring closure as is the case with the *trans*-dichlorides. Instead, it leads to the isomerization of the *cis*-K₂[Pt(β-Ala)₂I₂] and the formation of the *trans*-K₂[Pt(β-Ala)₂I₂]. After heating for 10 hours, the solution only contains one form of δ(¹⁹⁵Pt) = -3408 ppm. This new form was isolated as a single crystal and identified by the X-ray diffraction analysis, which confirmed that it was the *trans*-K₂[Pt(β-Ala)₂I₂].

To synthesize the *cis*-[Pt(β-Ala)₂], a solution of AgNO₃ was added to the solution of the *cis*-K₂[Pt(β-Ala)₂I₂]. The resulting AgI precipitate was filtered off. The filtrate solution contained only one form of the *cis*-[Pt(β-Ala)₂] complex (δ(¹⁹⁵Pt) = -1923 ppm).

TABLE 1: NMR spectral data for β -AlaH and the Pt(II) and Pd(II) complexes with β -AlaH.

Complex (solvent)	^{195}Pt NMR, δ , ppm	^1H NMR, δ , ppm				^{13}C NMR, δ , ppm		
		NH_2	$\text{CH}_2\text{-NH}_2$	$\text{CH}_2\text{-COO}$	COOH	COO^-	$\text{CH}_2\text{-NH}_2$	$\text{CH}_2\text{-COO}$
$\text{NH}_3^+(\text{CH}_2)_2\text{-COO}^-$ (D_2O)	—	—	3,10	2,48	179,1	37,30	34,29	
<i>Trans</i> -[Pt(β -AlaH) $_2$ Cl $_2$] (acetone- d_6)	-2248	4,29 $^2J_{\text{H-Pt}} = 50$ Hz	2,98	2,91	172,9	41,90	33,36	
<i>Trans</i> -[Pd(β -AlaH) $_2$ Cl $_2$] (acetone- d_6)	—	3,45	2,93	2,87	172,7	40,57	34,01	
<i>Trans</i> -[Pt(β -Ala) $_2$] (D_2O)	-1708	—	2,81	2,44	—	—	—	
<i>Cis</i> -[Pt(β -Ala) $_2$] (D_2O)	-1930	5,17* $^2J_{\text{H-Pt}} = 60$ Hz	2,76 $^2J_{\text{H-Pt}} = 45$ Hz	2,43	180,2	41,87 $^2J_{\text{C-Pt}} = 30$ Hz	36,36 $^3J_{\text{C-Pt}} = 22$ Hz	
<i>Trans</i> -[Pd(β -Ala) $_2$] (D_2O)	—	—	2,49	2,38	181,7	38,48	37,82	
<i>Cis</i> -[Pd(β -Ala) $_2$] (D_2O)	—	4,34*	2,59	2,46	180,6	39,86	37,04	

* Residual NH_2 protons.SCHEME 2: Sequence of reactions of $\text{K}_2[\text{PtI}_4]$ with β -alanine.

In addition to the main product, the *cis*-[Pt(β -Ala) $_2$], the solution contained KCl and KNO_3 . We added acetone to the reaction mixture (water : acetone \sim 1 : 2) to separate the desired product from inorganic salts. *Cis*-[Pt(β -Ala) $_2$] was the only substrate that precipitated under such conditions.

PMR spectra (Table 1)

The PMR spectrum of β -AlaH (Figure 1(a)) in D_2O contains two triplets of two CH_2 groups. The spectrum corresponds to an A_2X_2 four-spin system with magnetically equivalent protons in each CH_2 group [17, page 54].

Figure 1 shows that the coordinate β -alanine (spectra b, c, and d) has a more complex spectrum than the incoordinate β -alanine (spectrum a) in the region of CH_2 protons. The spectrum contains more lines, and their intensities are

TABLE 2: IR spectral data for the Pt(II) & Pd(II) complexes with β -Alanine.

Complex	$\tilde{\nu}$ (NH), cm^{-1}	$\tilde{\nu}$ (C = O), cm^{-1}
<i>Trans</i> -[Pt(β -AlaH) $_2$ Cl $_2$]	3285 3208	3254 3127
<i>Trans</i> -[Pd(β -AlaH) $_2$ Cl $_2$]	3319	3260 3128
<i>Trans</i> -[Pt(β -Ala) $_2$]	3268 3184	3215 3090
<i>Trans</i> -[Pd(β -Ala) $_2$]	3225	3038
<i>Cis</i> -[Pt(β -Ala) $_2$]	3235	3047
<i>Cis</i> -[Pd(β -Ala) $_2$]	3233	3080 3037
<i>Trans</i> - K_2 [Pt(β -Ala) $_2$ I $_2$]	3246	3190 3069

distorted. This indicates that the protons of both CH_2 groups are magnetically nonequivalent. Therefore, these spectra cannot be interpreted using first order rules [17, page 57].

It should be noted that the spectrum of the *trans*-[Pd(β -AlaH) $_2$ Cl $_2$] is similar to that of the *trans*-[Pt(β -AlaH) $_2$ Cl $_2$]. For both spectra (Figure 1(b)), it is impossible to evaluate the chemical shifts of the individual CH_2 groups from the spectra. In order to do that we should employ a six-spin system of $\text{AA}'\text{BB}'\text{X}_2$ type, where AA' and BB' are magnetically nonequivalent protons of the two CH_2 groups, and X_2 are magnetically equivalent NH_2 protons. In this system, the protons of the CH_2 group, which is related to NH_2 group, are additionally split at the NH_2 protons. After the suppression of interaction with the NH_2 protons, the PMR spectrum (Figure 1(c)) corresponds to an $\text{AA}'\text{BB}'$ four-spin system, is symmetric, and allows us to estimate the chemical shifts of the CH_2 groups on the center of each multiplet [17, page 200].

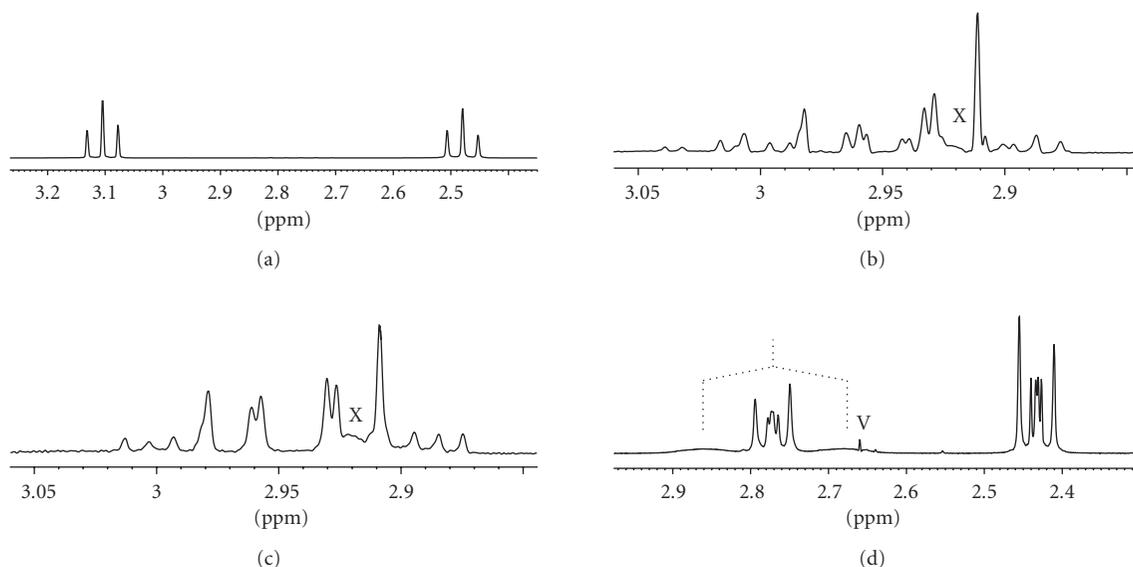


FIGURE 1: (a) PMR spectra in the region of CH₂ protons recorded in D₂O for β -AlaH; (b) PMR spectra in the region of CH₂ protons recorded in acetone-d₆ for $trans$ -[Pt(β -AlaH)₂Cl₂]; (c) PMR spectra in the region of CH₂ protons recorded in acetone-d₆ with NH₂ proton coupling suppression for $trans$ -[Pt(β -AlaH)₂Cl₂]; (d) PMR spectra in the region of CH₂ protons recorded in D₂O for cis -[Pt(β -Ala)₂]. X: broadened signal of the H₂O admixture in acetone (spectra b and c); V: DMSO reference in D₂O (spectrum d); \ddagger : broadened doublet of splitting at ¹⁹⁵Pt (spectrum d).

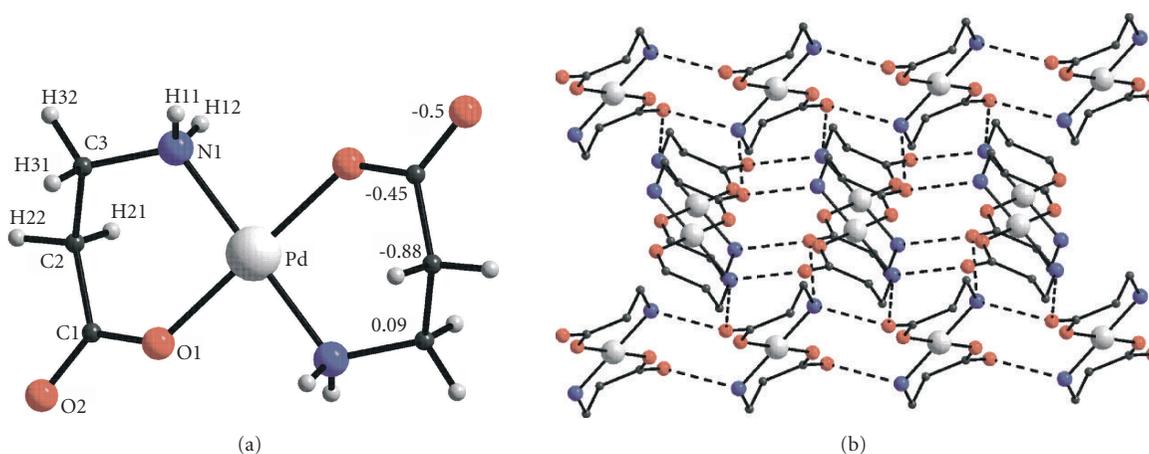


FIGURE 2: Molecular structure of $trans$ -[Pd(β -Ala)₂], atomic numbering, and deviations of atoms (Å) from the plane of the coordination square (a); view of the framework in the structure of complex (b).

Figure 1(d) shows the PMR spectrum of the cis -[Pt(β -Ala)₂] in D₂O. The spectrum only contains the signals of two CH₂ groups (the NH₂ protons are deuterated in D₂O and do not display in the spectrum). The PMR spectra of bischelates as well as those of dichlorides allow us to evaluate the chemical shifts of the individual CH₂ groups on the centers of multiplets.

The spectrum of the cis -[Pt(β -Ala)₂] also shows that the weak-field signal of the CH₂ group combined with the NH₂ group is split at ¹⁹⁵Pt (broadened doublet).

It should be noted that for the Pt and Pd cis -bischelates we succeeded in recording the signals of the NH₂ protons in

D₂O because the NH₂ protons are deuterated in the $trans$ -bischelates faster than in the cis -bischelates.

¹⁹⁵Pt NMR spectra (Table 1)

The ¹⁹⁵Pt signal in the spectrum of the $trans$ -[Pt(β -AlaH)₂Cl₂] is found in the region of $\delta \sim -2200$ ppm, as is the case with the other similar compounds with α -amino acids. The difference between the chemical shifts of the cis - and $trans$ -bischelate complexes is up to 200 ppm, the signals of the $trans$ -bischelates lying in a weaker field. Such differences are also observed for the bischelates with α -amino acids [18].

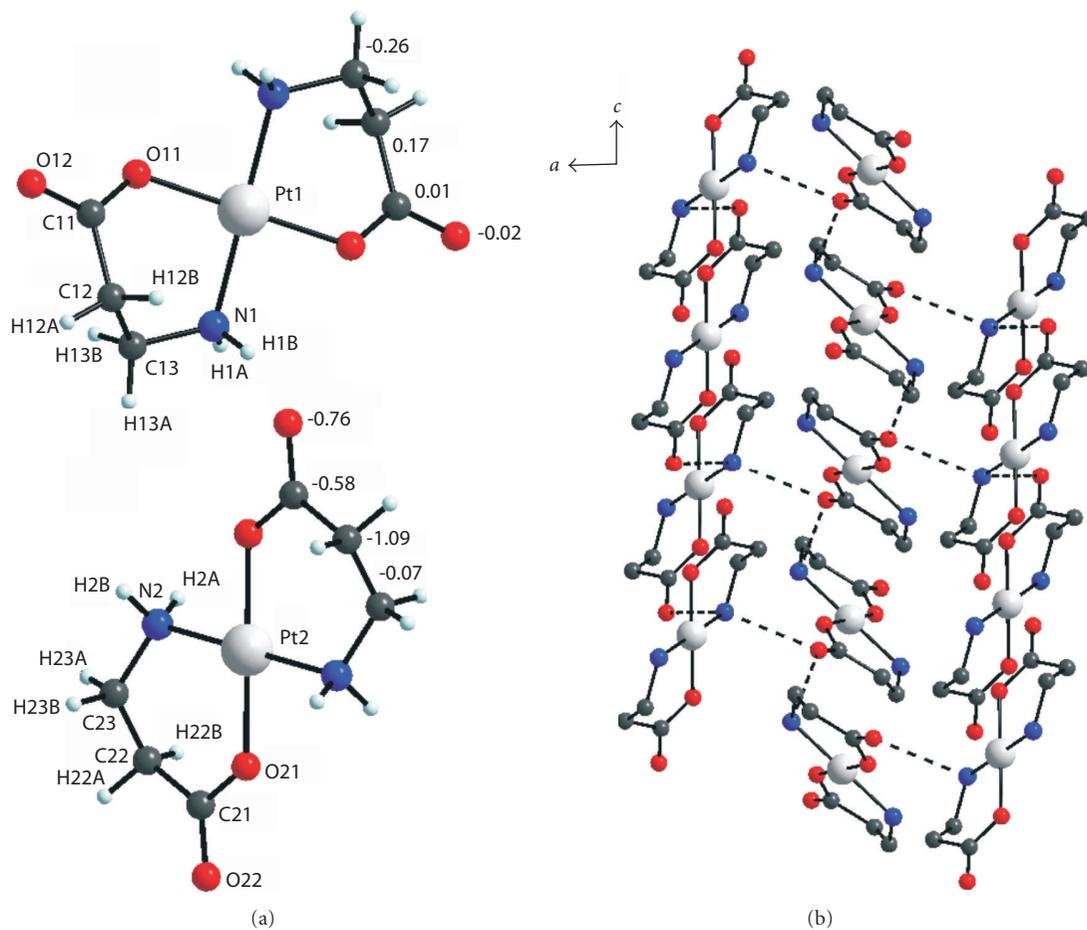


FIGURE 3: Molecular structure of Pt1 and Pt2 in *trans*-[Pt(β -Ala)₂] (a); structure projected on the (001) plane (b).

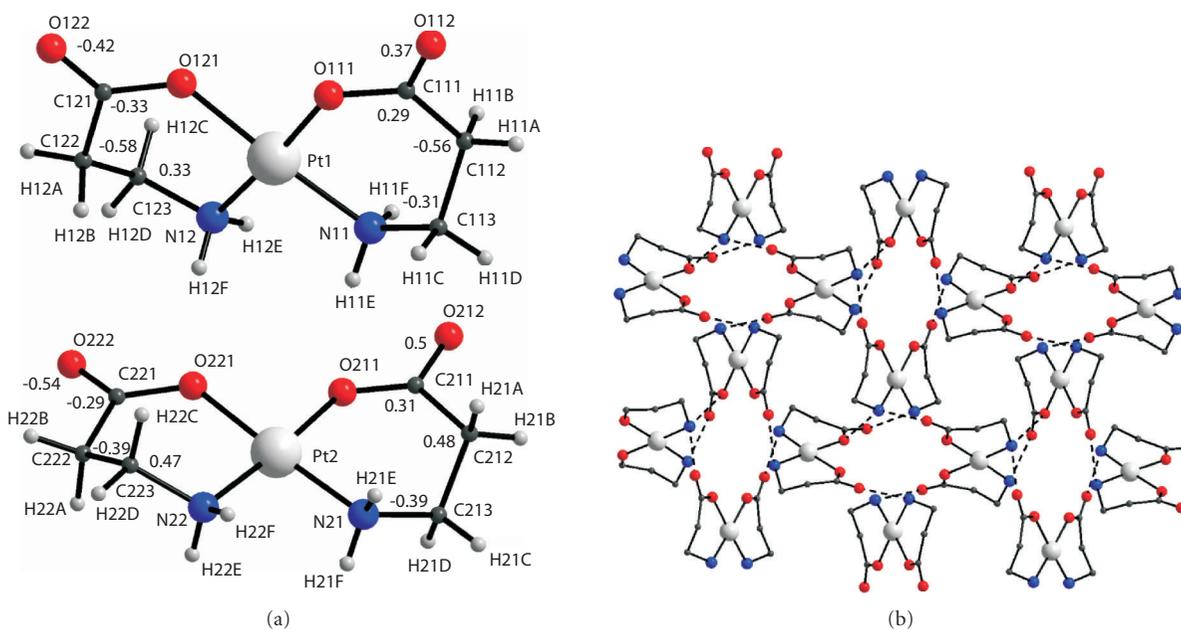


FIGURE 4: Molecular structure of Pt1 and Pt2 in *cis*-[Pt(β -Ala)₂] and deviations of atoms (Å) from plane of the coordination square (a); structure of a layer (b).

TABLE 3: Selected stereochemical data for the studied compounds.

	<i>Trans</i> -[Pd(β -Ala) ₂]	<i>Trans</i> -[Pt(β -Ala) ₂]	<i>Cis</i> -[Pt(β -Ala) ₂]	K ₂ [Pt(β -Ala) ₂ I ₂]•2H ₂ O
Pt–O	2.004(2) 2.004(2)	1.997(5) 1.996(6)	1.994(7) 2.033(7) 2.019(7) 2.014(8)	—
Pt–N	2.026(2) 2.026(2)	2.031(7) 2.026(8)	1.979(9) 2.015(8) 1.986(9) 2.009(7)	2.047(5)
Pt–Hal	—	—	—	2.5902(5)
K–I	—	—	—	3.797(1) 4.285(2)
K–O	—	—	—	2.780(4) 2.820(5) 2.808(5) 2.863(5) 2.851(4)
\angle NPtO	94.35(8)	94.0(3)	95.1(3) 95.0(3) 96.1(3) 94.9(3)	—
C–O	1.291(3) 1.232(2)	1.290(11) 1.235(11) 1.281(10) 1.221(11)	1.291(15) 1.188(15) 1.308(13) 1.186(14) 1.259(14) 1.252(14) 1.317(13) 1.219(14)	1.249(7) 1.255(7)
C–N	1.463(3)	1.486(11) 1.461(14)	1.525(15) 1.461(15) 1.539(14) 1.468(14)	1.489(8)

It should be noted that the signals of *cis*- and *trans*-bischelates with β -alanine lie in a stronger field compared to the signals of similar α -amino acid complexes, the difference being up to 60–70 ppm.

¹³C NMR spectra (Table 1)

The spectrum of the *trans*-[Pt(β -Ala)₂] could not be recorded because of the very low solubility of this compound in water.

Table 1 shows that the ¹³C signals of the protonated COOH group in the *trans*-[M(β -AlaH)₂Cl₂] (M = Pt, Pd) lie in a stronger field than the signals of the coordinate COO groups in the *cis*- and *trans*-bischelate complexes of Pt(II) and Pd(II).

IR spectra (Table 2)

As is known, for free amino acids, which exist as bipolar NH₃⁺CH(R)COO⁻ ions, there is a broad band of up to 3400 cm⁻¹ in the region of the N = H ($\tilde{\nu}$ (NH)) stretching vibrations, while the C = O ($\tilde{\nu}$ (CO)) stretching vibrations display in the region of 1600 cm⁻¹.

For the coordinated α -amino acids in the Pt(II) and Pd(II) bischelate complexes, the $\tilde{\nu}$ (CO) is recorded in the region of 1650 cm⁻¹, while the $\tilde{\nu}$ (NH) is found at 3200 cm⁻¹. For example, for the Pt(II) *trans*-bischelate with glycine, the $\tilde{\nu}$ (CO) is equal to 1643 cm⁻¹, and the $\tilde{\nu}$ (NH) is equal to 3230 and 3090 cm⁻¹. For the similar Pd(II) complex, the $\tilde{\nu}$ (CO) equals 1642 cm⁻¹, and the $\tilde{\nu}$ (NH) equals 3230 and 3120 cm⁻¹ [19].

For all complexes presented in this work, the split lines of NH antisymmetric stretching vibrations in the region of ~3200 cm⁻¹ were found as well as NH symmetric stretching vibrations at ~3100 cm⁻¹, that correspond to the coordinated NH₂ group.

In the region of the C = O stretching vibrations for the Pt(II) and Pd(II) bischelates, the $\tilde{\nu}$ (CO) is in the range of 1617–1640 cm⁻¹, which shows that the OCO group is coordinate.

For the *trans*-K₂[Pt(β -Ala)₂I₂] complex with the incoordinate COO group, the $\tilde{\nu}$ (CO) is equal to 1602 cm⁻¹, as is the case with free amino acids.

For the *trans*-[M(β -AlaH)₂Cl₂] complexes (where M = Pt, Pd) containing the monodentate ligands of β -AlaH, which is coordinated via the NH₂ group and contains the protonated COOH group, the stretching vibrations, the $\tilde{\nu}$ (C = O), reach up to 1710 cm⁻¹, as for similar compounds with α -amino acids [19].

X-ray diffraction data (Table 3)

In the *trans*-[Pd(β -Ala)₂] centrosymmetric molecule (Figure 2(a)), the Pd–O and Pd–N distances are 2.004 and 2.026 Å. The deviations of atoms from the plane of the chelate ring may be as high as 0.88 Å (for α -C). The chelate angle is 94.35°, which corresponds to the transannular distance O···N 2.958 Å. The hydrogen bonds between the NH₂ groups and the incoordinate atoms of carboxyl O groups link the molecules into a framework (Figure 2(b)).

In the structure of the *trans*-[Pt(β -Ala)₂], both of the crystallographically independent molecules are also

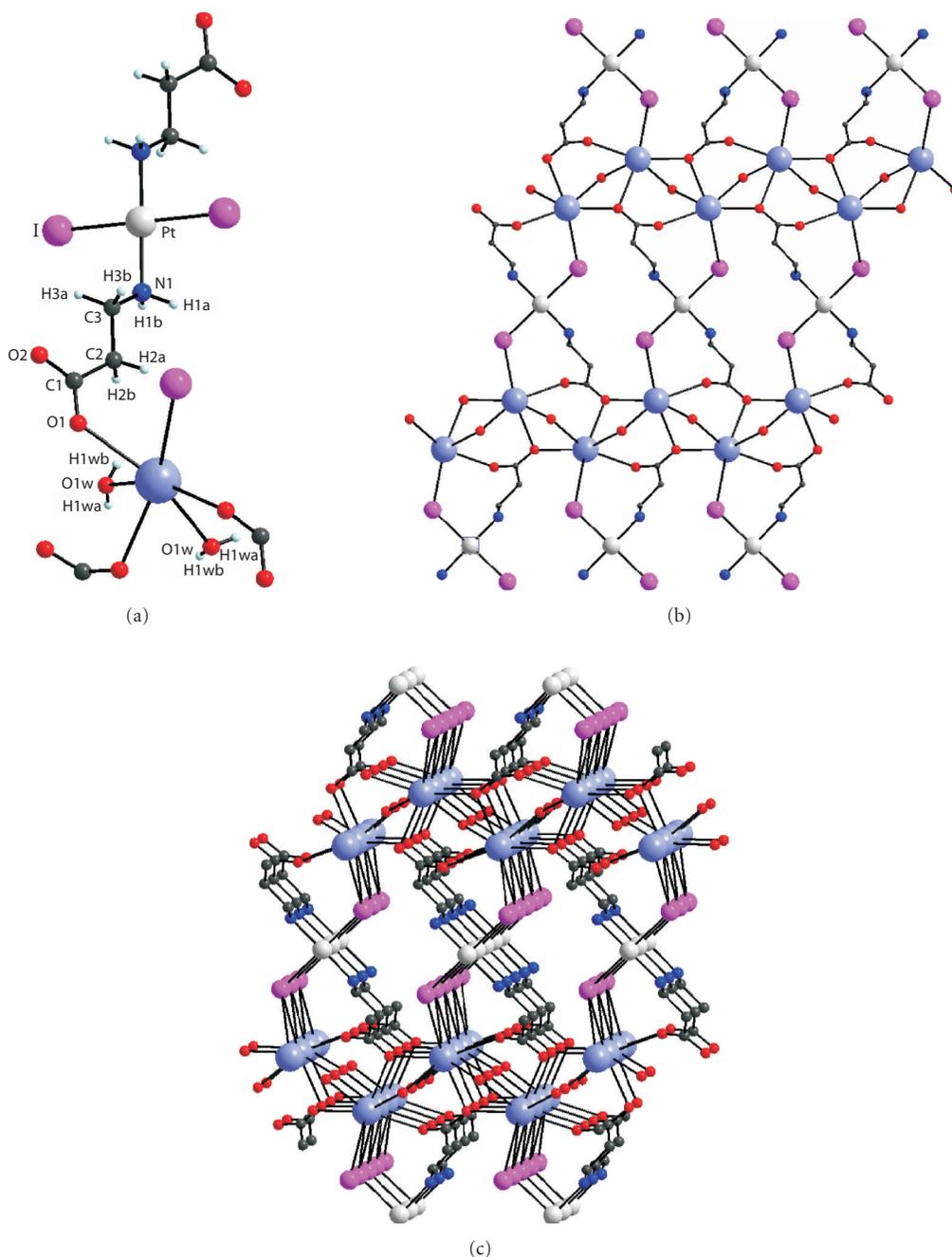


FIGURE 5: Atomic numbering scheme in an independent fragment (a); structure of the layer (b), and structure of the framework (c) in $trans\text{-K}_2[\text{Pt}(\beta\text{-Ala})_2\text{I}_2]\cdot 2\text{H}_2\text{O}$.

centrosymmetric. The Pt(II) atom is surrounded by a square formed by the N donor atoms of the amino groups and the O atoms of the two alaninate anions (Figure 3(a)). The average Pt–O and Pt–N bond lengths are 1.996 and 2.028 Å, respectively. As in the $trans\text{-}[\text{Pd}(\beta\text{-Ala})_2]$, the C–O distances for the coordinate O atom of the deprotonated OH group are appreciably longer than those for the incoordinate atoms (1.29 and 1.23 Å on the average). The independent molecules differ in the configuration of the chelate rings. The maximal deviation of nonhydrogen atoms from the plane

of the coordination square is 0.26 Å in the Pt1 molecule and 1.09 Å in the Pt2 molecule (Figure 3(a)). The N–Pt–O chelate angle in the Pt2 molecule, which is “more planar,” is $95.7(3)^\circ$; this is much larger than in the Pt1 molecule ($94.0(3)^\circ$).

The molecules in the structure are hydrogen bonded into a framework by N–H \cdots O type bonds (Figure 3(b)).

In the crystallographically independent $cis\text{-}[\text{Pt}(\beta\text{-Ala})_2]$ molecules the metal atom also has square planar surroundings (Figure 4(a)). The average values of the Pt–O and Pt–N bond lengths are 2.015 and 1.997 Å, respectively.

The maximal deviation of nonhydrogen atoms from the coordination square plane is 0.58 Å in the Pt1 molecule and 0.54 Å (Figure 4(a)) in the Pt2 molecule. The hydrogen bonds link the molecules into layers (Figure 4(b)).

In the *trans*-K₂[Pt(β-Ala)₂I₂]*2H₂O complex, the coordination *trans*-square of Pt is formed by two I atoms and by the N atoms of the β-alaninate ions. The Pt–I distance is 2.5902(5) Å, and the Pt–N distance is 2.047(5) Å. The N···O distance in β-Ala is 4.197 Å. The carboxylate groups of the β-alaninate ions link the [Pt(β-Ala)₂I₂] fragments with K⁺ ions, thus forming polymer layers in the structure (Figure 5). The environment of the K ion includes three O atoms of the carboxylate groups, two O atoms of the water molecules (*d*_{K–O} = 2.780(4) – 2.863(5) Å), and two I ions (*d*_{K–I} = 3.797(1) and 4.285(2) Å), because of which the layers are linked into a framework.

4. CONCLUSION

First, the techniques have been developed of the synthesis of bisaminoacid complexes Pt(II) and Pd(II): (1) the interaction of K₂[PtCl₄] or Na₂[PdCl₄] with β-alanine resulted in the *trans*-isomers only; (2) the synthesis of the *cis*-[Pt(β-Ala)₂] can be done by the interaction of K₂[PtI₄] with β-alanine; (3) for the synthesis of the *cis*-[Pd(β-Ala)₂], we have used the kinetic and thermodynamic data for the *trans*-*cis* isomerization of the Pd(II) bischelates with α-amino acid. Second, the investigation of the NMR, IR spectral, and crystal structures have been reported for the individual isomers: the *trans*-[M(β-AlaH)₂Cl₂] and the *cis*-[M(β-Ala)₂] (M = Pt, Pd).

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