Crystal Structures of trans–Diodidobis(2–hydroxyethylamine) platinum(II) and trans–Dichloridobis(2,2′–dihydroxydiethylamine) platinum(II)

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The crystal structures of trans-diiodidobis(2-hydroxyethylamine)platinum(II), trans-[PtI₂(mea)₂], (I) and trans-dichloridobis(2,2′-dihydroxydiethylamine)platinum(II), trans-[PtCl₂(dea)₂], (2) were determined by single crystal X-ray diffraction experiments. Crystallization of (I) occurs in the monoclinic space group P2₁/c with a = 9.457(1) Å, b = 14.719(2) Å, c = 8.246(1) Å, Z = 4 for d calc = 3.235 mg/m³ while crystallization of (2) occurs in the tetragonal space group P4 /mbc, a = 9.8624(6) Å, c = 14.2998(9) Å, Z = 4 for d calc = 2.274 mg/m³. The square-planar coordination geometry of both complexes is formed by two N atoms of the 2-hydroxyethylamine (I) or 2,2′-dihydroxydiethylamine (2) ligands in trans positions and two I⁻ (I) or Cl⁻ (2) anions. Both structures are stabilized by intra- and intermolecular hydrogen bonds.

Keywords: Platinum(II) complexes, 2-hydroxyethylamine, 2,2′-dihydroxydiethylamine.

Кристаллические структуры транс–дийодидобис–(2–гидроксизетиламина)платины(II) и транс–дихлоридобис–(2,2′–дигидроксидиэтиламина)платины(II)

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С помощью рентгеноструктурного анализа были определены кристаллические структуры транс–дийодидобис(2-гидроксизетиламина)платины(II), trans-[PtI₂(mea)₂], (I) и транс–дихлоридобис(2,2′–дигидроксидиэтиламина)платины(II), trans-[PtCl₂(dea)₂], (2). Молекула (I) кристаллизуется в моноклинной пространственной группе P2₁/c, где a = 9.457(1) Å, b = 14.719(2) Å, c = 8.246(1) Å, Z = 4 для d calc = 3.235 мол/л³, молекула (2) – в тетрагональной пространственной группе P4 /mbc, где a = 9.8624(6) Å, c = 14.2998(9) Å, Z = 4 для d calc = 2.274 мол/л³. Плоскоквадратная координационная геометрия обоих комплексов образована двумя атомами азота лигандов 2-гидроксизетиламина (I) или 2,2′-дигидроксидиэтиламина (2) в транс-положениях и двумя анионами I⁻ (I) или Cl⁻ (2). Обе структуры стабилизированы внутри- и межмолекулярными водородными связями.

Ключевые слова: Комплексы платины(II), 2-гидроксизетиламина, 2,2′-дигидроксидиэтиламина.
Discovery of cisplatin as cancerostatic compound and successful clinical application of it, developed widespread interest of synthesis of different platinum complexes with potential antitumor activity. The platinum(II) complexes with bis(2-hydroxyethy lamine) and bis(2,2'-dihydroxydiethylamine) ligands gained great interest because of the ability of the hydroxyl groups to act as acceptors or donors for hydrogen bonds, which is expected to play an important role in the binding of platinum complexes to DNA.[1-4] The modified literature method was used for the synthesis of trans-diiodidobis(2-hydroxyethylamine)platinum(II) and trans-dichloridobis(2-hydroxyethylamine)platinum(II).[5]

**Synthesis**

trans-[PtI₂(mea)] (1). Into suspension of PtI₂ (0.05 g, 0.10 mmol) in 10 ml of water 10.40 μl (0.20 mmol) of 2-hydroxyethylamine was added. The solution was stirred at 60–70 °C for several hours. pH was kept at 4.5–5.0 by adding of 0.10 M HClO₄. The color of the solution was changed from dark-violet to dark-yellow and was left at room temperature to evaporate (Scheme 1). The dark-yellow needles crystals were obtained (yield 36.6 mg, 64 %). Recrystallization was from methanol:water (60/40, v/v). Found: H 4.59, C 20.03, N 5.92 %. C H₂N-O requires H 4.66, C 20.18, N 5.88 %. IR (KBr) ν max cm⁻¹: 3412 ν(O-H), 3200 ν(N-H), 2970-2940 ν(C-H), 1618-1650 δ(N-H). UV-Vis λ max nm: 390.47. \( ^1 \)H NMR (200 MHz, D₂O) δ ppm: 3.88 (2H, t, CH₂-OH, J = 5.27 Hz), 3.14 (2H, t, CH₂-NH₂, J = 5.27 Hz).

trans-[PtCl₂(dea)] (2). Into aqueous solution of K₂[PtCl₄] (0.1 g, 0.24 mmol) 50 μl (0.48 mmol) of 2,2'-dihydroxydiethy lamine was added. The solution was stirred at 60–70 °C for several hours. pH was kept at 4.5–5.0 by adding of 0.10 M HClO₄. The color of the solution was changed from dark-red to dark-orange and was left at room temperature to evaporate (Scheme 2). The dark-orange crystals were obtained (yield 60.6 mg, 53 %). The complex was recrystallized from 5 ml mixture of the methanol:water (50/50, v/v). Found: H 4.59, C 20.03, N 5.92 %. C H₂Cl₂N-Opt requires H 4.66, C 20.18, N 5.88 %. IR (KBr) ν max cm⁻¹: 3412 ν(O-H), 3200 ν(N-H), 2970-2940 ν(C-H), 1618-1650 δ(N-H). UV-Vis λ max nm: 384.02. \( ^1 \)H NMR (200 MHz, D₂O) δ ppm: 3.82 (2H, t, CH₂-OH, J = 5.27 Hz), 3.14 (2H, t, CH₂-NH₂, J = 5.27 Hz).

**Structure Determination**

Crystallographic data for complexes 1 and 2 are summarized in Table 1. X-Ray diffraction data were collected at 100 K on a Bruker-Nonius KappaCCD diffractometer using MoKα radiation (\( \lambda = 0.71073 \) Å, graphite monochromator). Absorption corrections were performed on a semi-empirical basis from multiple scans with SADABS.[6] The structures were solved by direct methods and refined by full-matrix least-squares procedures on \( F^2 \) in the anisotropic approximation for all atoms except hydrogen. Space groups were assigned according to the numbers in International Tables.[6]

The complex molecule of trans-[PtCl₂(dea)] (2) was situated on a fourfold symmetric crystallographic site (Wyckoff position 4a with a 2/m site symmetry). The OH group was disordered with a refined occupancy of the two alternative sites of 46(2) and 54(2) %. Attempts to refine the data in space group \( P4/ mcm \) resulted in disorder of all atoms except Pt, significantly worse values and geometric parameters. All hydrogen atoms were placed in positions of optimized geometry. The isotropic displacement parameters of the H atoms were tied to those of their adjacent carrier atoms by a factor of either 1.2 or 1.5.

In the structure of trans-[PtI₂(mea),] complex the atoms around the platinum center are arranged in a square-planar manner (Figure 1). The Pt(1)-N(1), Pt(1)-N(2), Pt(1)-I(1) and Pt(1)-I(2) distances are in the normal range.[5] The angular sum of equatorial atoms are 360.01°. The N(1)-Pt(1)-N(2) and I(1)-Pt(1)-I(2) angles are 179.56(12) and 177.392(9), respectively. The small deformation of the I(1)-Pt(1)-I(2) angle from the ideal value of 180° is due the space requirements of the I ligands (Table 2).

The N-H group participates in a interaction leading to an intermolecular N(1)-H(1A)···O(1) hydrogen bond in complex (1) (Table 3).

In the structure of trans-[PtCl₂(dea)], complex the coordination sphere of the central Pt(II) ion is comprised by two nitrogen donor atoms (from two 2,2'-dihydroxydiethylamine ligands) trans to each other and two chlorido ligands also in trans position. The molecule itself is located on a crystallographic twofold axis parallel to the z-direction and exhibits therefore \( C₂ \) symmetry (Figure 2). The geometry of the complex is almost ideally square-planar.

The Pt-N (2.041(7) Å) and Pt-Cl (2.302(2) Å) distances are in the range of distances reported previously for the isomorphous Pd(II) analog (Table 4).[7]

**Scheme 1.** Synthesis of trans-diiodidobis(2-hydroxyethylamine)platinum(II).

**Scheme 2.** Synthesis of trans-dichloridobis(2,2'-dihydroxydiethylamine)platinum(II).
Crystal Structures of MEA and DEA Platinum(II) Complexes

Table 1. Crystal data, data collection and refinement details for (1) and (2).

|                       | \(\text{trans-}[\text{PtI}_2(\text{mea})_2] \) (1) | \(\text{trans-}[\text{PtCl}_2(\text{dea})_2] \) (2) |
|-----------------------|-----------------------------------------------|-----------------------------------------------|
| Molecular Formula     | \( \text{C}_4\text{H}_{14}\text{I}_2\text{N}_2\text{O}_2\text{Pt} \) | \( \text{C}_8\text{H}_2\text{Cl}_2\text{N}_2\text{O}_4\text{Pt} \) |
| Mol. Weight           | 571.06                                        | 476.27                                        |
| Color, shape          | dark-yellow, needles                          | dark-orange, block                            |
| Crystal size (mm)     | 0.20×0.11×0.07                                | 0.28×0.22×0.18                                |
| Crystal system        | Monoclinic                                    | Tetragonal                                    |
| Space group           | \( P2_1/c \)                                  | \( P4/mnb \)                                  |
| \( a \) (\(\AA\))    | 9.757(1)                                      | 9.8624(6)                                    |
| \( b \) (\(\AA\))    | 14.719(2)                                     | 9.8624(6)                                    |
| \( c \) (\(\AA\))    | 8.246(1)                                      | 14.2998(9)                                   |
| \( \beta \) (°)       | 98.07(1)                                      | 90                                           |
| \( V \) (\(\AA^3\))  | 1172.5(2)                                     | 1390.9(2)                                    |
| \( Z \)               | 4                                             | 4                                            |
| \( d_{\text{calc}} \) (mg/m\(^3\)) | 3.235                                        | 2.274                                        |
| \( F(000) \)          | 17.200                                        | 10.477                                       |
| \( T_{\text{min}}; T_{\text{max}} \) | 0.123; 0.300                                 | 0.062; 0.150                                 |
| \( \theta \) range for data collection (°) | 3.48–29.57                                    | 4.08–28.70                                   |
| Limiting indices      | \(-13 \leq h \leq 13\)                       | \(-13 \leq h \leq 13\)                       |
|                       | \(-20 \leq k \leq 20\)                      | \(-13 \leq k \leq 11\)                      |
|                       | \(-11 \leq l \leq 11\)                      | \(-19 \leq l \leq 19\)                      |
| Reflection collected  | 19792                                         | 19860                                        |
| Independent reflection| 3232 (\(R_{\text{int}} = 0.0327\))           | 939 (\(R_{\text{int}} = 0.0483\))           |
| Refinement method     | Full-matrix least-squares on \( F^2 \)       | Full-matrix least-squares on \( F^2 \)       |
| Refined parameters    | 103                                            | 62                                           |
| Absorption correction | Semi-empirical from equivalents               | Semi-empirical from equivalents               |
| Goodness-of-fit on \( F^2 \) (all data) | 1.156                                         | 1.329                                        |
| Final \( R \) indices \([I = 2\sigma(I)]\) | \( R_{\text{i}} = 0.0210, wR_{\text{2}} = 0.0386 \) | \( R_{\text{i}} = 0.0266, wR_{\text{2}} = 0.0638 \) |
| \( R \) indices (all data) | \( R_{\text{i}} = 0.0287, wR_{\text{2}} = 0.0398 \) | \( R_{\text{i}} = 0.0366, wR_{\text{2}} = 0.0671 \) |
| Extinction coefficient | 0.00062(5)                                    | /                                            |
| Largest diff. peak and hole (eÅ \(^{-3}\)) | 0.941; −0.900                                 | 0.843; −1.249                                |

Figure 1. ORTEP drawing (left) and ball-and-stick representation (right) of complex (1) with the applied atomic numbering scheme and thermal ellipsoids at 50% probability level and H atoms are shown as small spheres or arbitrary radii.
Table 2. Selected bond distances (Å) and angles (°) for \textit{trans}-[PtI\(_2\)(mea)\(_2\)] complex.

| Distances (Å) | Angles (°) |
|---------------|------------|
| Pt(1)-N(1)   | 2.048(3) N(1)-Pt(1)-N(2) | 179.56(12) |
| Pt(1)-N(2)   | 2.052(3) N(1)-Pt(1)-I(1) | 89.34(9)   |
| Pt(1)-I(1)   | 2.6005(4) N(2)-Pt(1)-I(1) | 90.81(9)   |
| Pt(1)-I(2)   | 2.6041(4) N(1)-Pt(1)-I(2) | 90.53(9)   |
| O(1)-C(2)    | 1.426(5)  N(2)-Pt(1)-I(2) | 89.34(9)   |
| O(2)-C(4)    | 1.431(5)  I(1)-Pt(1)-I(2) | 177.392(9) |
| N(1)-C(1)    | 1.492(4)  C(1)-N(1)-Pt(1) | 117.0(2)   |
| N(2)-C(3)    | 1.483(5)  C(2)-N(2)-Pt(1) | 116.7(2)   |
| C(1)-C(2)    | 1.515(5)  C(1)-C(2)-Pt(1) | 109.7(3)   |
| C(3)-C(4)    | 1.518(5)  C(2)-C(3)-Pt(1) | 109.9(3)   |
| O(1')-C(2)   | 0.91      O(1)-C(2)-C(1) | 110.5(3)   |
| O(2)-C(4)-C(3)| 2.40      O(2)-C(4)-C(3) | 107.0(3)   |

The hydroxyl and N-H groups from the 2,2'-dihydroxydiethylamine are involving in very strong hydrogen bonding interaction between complex units (Table 5).

The crystal packing structure of \textit{trans}-[PtCl\(_2\)(dea)\(_2\)] viewed down the crystallographic \textit{b} axis is shown in Figure 3.

In both synthesized complexes the atoms around the platinum center are arranged in a square-planar manner. The X-ray study confirmed almost ideal square-planar geometry for the \textit{trans}-[PtI\(_2\)(mea)\(_2\)] complex. In the complex \textit{trans}-[PtI\(_2\)(mea)\(_2\)] a small deformation of the I(1)-Pt(1)-I(2) angle is observed due the space requirements of the I\(_-\)ligands. Both structures are stabilized by intramolecular hydrogen bonds related to hydroxyl and chlorido groups which act as acceptors or donors for hydrogen bonds.

Table 3. Geometrical parameters for hydrogen bond for (I) complex.

| Hydrogen bond         | d(D-H) (Å) | d(H···A) (Å) | d(D···A) (Å) | <(D-H···A) (°) |
|-----------------------|------------|-------------|-------------|---------------|
| (I) N(1)-H(1A)···O(1) | 0.91       | 2.40        | 2.843(4)    | 110           |

Figure 2. ORTEP drawing (left) and ball-and-stick representation (right) of complex (2) with the applied atomic numbering scheme and thermal ellipsoids at 50 % probability level and H atoms are shown as small spheres or arbitrary radii.

Table 4. Selected bond distances (Å) and angles (°) for \textit{trans}-[PtCl\(_2\)(dea)\(_2\)] complex.

| Distances (Å) | Angles (°) |
|---------------|------------|
| Pt(1)-N(1)    | 2.041(7)   | N(1)-Pt(1)-N(1) | 180.0 |
| Pt(1)-N(1)    | 2.041(7)   | N(1)-Pt(1)-Cl(1)| 87.8(2) |
| Pt(1)-Cl(1)   | 2.302(2)   | N(1)-Pt(1)-Cl(1)| 92.2(2) |
| Pt(1)-Cl(1)#1 | 2.302(2)   | N(1)-Pt(1)-Cl(1)#1 | 92.2(2) |
| O(1)-C(2)     | 1.312(15)  | N(1)-Pt(1)-Cl(1)#1 | 87.8(2) |
| O(1')-C(2)    | 1.297(11)  | Cl(1)-Pt(1)-Cl(1)#1 | 180.0 |
| N(1)-Cl(1)    | 1.519(7)   | Cl(1)-Pt(1)-Cl(1)#1 | 107.4(6) |
| N(1)-Cl(1)#2  | 1.519(7)   | Cl(1)-N(1)-Pt(1) | 114.8(4) |
| C(1)-C(2)     | 1.520(8)   | C(1)-N(1)-Pt(1) | 114.8(4) |
| C(1)-C(2)     | 1.520(8)   | C(1)-N(1)-Pt(1) | 114.8(4) |
| C(1)-C(2)     | 1.520(8)   | C(1)-N(1)-Pt(1) | 114.8(4) |
| C(1)-C(2)     | 1.520(8)   | C(1)-N(1)-Pt(1) | 114.8(4) |

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Dedication

This communication is dedicated to 75th birthday of extraordinary scientist and person Professor em. Dr. Dr. h. c. mult. Rudi van Eldik. The work is also dedicated to the memory of my great mentor, good person and excellent chemist Professor Dr. Živadin D. Bugarčić (1954–2017). T. V. Soldatović as a PhD student was witness of strong friendship between them. Thanks to Professor Dr. Živadin D. Bugarčić she was lucky to meet and to be part of Rudy’s research group.
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Table 5. Geometrical parameters for hydrogen bond for (2) complex.

| Hydrogen bond | d(D-H) (Å) | d(H···A) (Å) | d(D···A) (Å) | <(D-H···A) (°) |
|---------------|------------|--------------|--------------|---------------|
| N(1)-H(1A)...Cl(1)#3 | 0.93 | 2.86 | 3.484(7) | 124.0 |

Figure 3. Packing diagram in the unit cell of complex (2).

Crystallographic information: CCDC-2015320 for 1 and CCDC-2015319 for 2 contain the supplementary crystallographic data for compounds 1-8, respectively, in this paper. The data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/structures.

References

1. Wang D., Lippard S.J. Nat. Rev. Drug. Disc. 2005, 4, 307–320.
2. Lippert B. Cisplatin: Chemistry and Biochemistry of a Leading Anticancer Drug. Zürich: Wiley-VCH, 1999. 576 p.
3. Jamieson E.R., Lippard S.J. Chem. Rev. 1999, 99, 2467–2466.
4. Jakubec M.A., Galanski M., Keppler B.K. Rev. Physiol. Biochem. Pharmacol. 2003, 146, 1–53.
5. Zimmermann W., Galanski M., Keppler B.K., Giester G. Inorg. Chim. Acta 1999, 292, 127–130.
6. a) Wilson A.J.C. International Tables for Crystallography (Ed.) Dordrecht: Kluwer Academic Publishers, 1992, tables 6.1.4 (500–502), 4.2.6.8 (219–222), 4.2.4.2 (193–199); b) COLLECT Bruker-Nonius 2002 for data collection; c) EvalCCD, Bruker-Nonius 2002 for data reduction; d) SAD-ABS 2.06, Bruker-AXS 2002 for absorption correction; e) SHELXL 2018/3, Sheldrick G.M. Acta Crystallogr. 2015, C71, 1–8 for refinement; g) SHELXLNT 6.12, Bruker AXS 2002 for molecule projection.
7. Petrović Z.D., Djuran M.I., Heinemann F.W., Rajković S., Trifunović S.R. Bioorg. Chem. 2006, 34, 225–234.

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