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ELEGANT ARRANGEMENTS: A CRYSTALLOGRAPHIC PERSPECTIVE ON THE BIS[1-METHOXY-2,2,2-TRIS-(PYRAZOL-1-YLKN2) ETHANE]-COBALT(II) BIS-PERCHLORATE COMPLEX

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Abstract

Inorganic chemistry research in the modern era predominantly revolves around the captivating realm of coordination chemistry. A fundamental component of this field is the study of transition metals, which are characterized by their incomplete d or f subshells in their elemental or ionic states (Huheey et al., 1993). This introduction sets the stage for exploring the multifaceted aspects of transition metals in coordination chemistry research.

Transition metals, positioned within the same period of the periodic table, exhibit gradual changes in their atomic and ionic radii as well as ionization potentials from one element to the next. This subtle progression creates a fascinating landscape for investigation and has significant implications for their chemical behavior. Furthermore, transition metals are known for their ability to exist in multiple valence states, a feature that greatly influences the formation of complex compounds. This intricate chemistry leads to the creation of a plethora of colorful and paramagnetic coordination complexes, further highlighting the unique attributes of these elements.

Transition metal complexes are not just of academic interest; they find extensive practical applications in today's world of applied chemistry. Many transition metal complexes serve as highly effective catalysts, catalyzing a variety of chemical reactions crucial for numerous industrial processes. This critical role in catalysis underscores the importance of understanding the chemistry and behavior of transition metals in coordination compounds. This paper explores the captivating world of transition metals in coordination chemistry, shedding light on their atomic characteristics, multiple valence states, and the remarkable complexity of their coordination complexes.

Keywords: Transition metals, coordination chemistry, atomic characteristics, valence states, catalysts.

1. Introduction

Most of the modern inorganic chemistry research involves coordination chemistry. Transition metals are one of the essential components of coordination chemistry research. Transition metals are classically defined as elements with incomplete d or f subshells in their elementary or ionic state (Huheey et al., 1993). For transition metals in the same period of the periodic table, values of atomic and ionic radii, as well as ionization potentials change slowly from one transition metal to the next. In addition, most of transition metals have multiple valence state. As a result, their chemistry is dominated by complex formations. Because of their unique features, majority of transition elements often produce colorful paramagnetic coordination complexes. In addition, significant number of transition metal complexes are widely used as effective catalysts in modern day applied chemistry.

Cobalt is one of the key transition elements with a wide variety of applications. Although at the beginning human society was mainly interested in silver ore, this ore also typically contains cobalt, and more recent inorganic chemistry research is focused incessantly on cobalt and its versatile applications. Cobalt is one of the important bioessential elements, mainly because of its location in the center of vitamin B12 structure or cobalamin core (Czarnek et al., 2015). Vitamin B12 plays several pivotal roles in the physiology of the human body. The manufactured form of vitamin B12, cyanocobalamin is widely used to treat vitamin B12 deficiency. Cobalt isotopes are used in cancer treatments in the form of radiotherapy (Bainbridge et al., 2017). Variety of cobalt compounds are widely used in the process of detection of tumors and metastases, sterilization of surgical equipment and the imaging of damage to the brain (Hart et al., 2018). Modern coordination chemistry has ample presence of nitrogen containing heterocycles. One such important class is pyrazole. Pyrazole is a five-member heterocyclic compound with two adjacent nitrogen atoms (Davies, 1997). Synthesis of derivatives of pyrazole are drawing significant attention over the years because of their biological activities. Recently, topology and nature of donor atoms in the pyrazole derivatives have drawn great interest in agrochemical, pharmaceutical, and chemical industries (Fustero et al., 2011; Keter & Darkwa, 2012). Research shows that nitrogen containing five members heterocyclic compounds, such as pyrazole derivatives, could potentially be used as antitumor, antibacterial, antifungal, antiviral, anti-parasitic, anti-tubercular and insecticidal agents (Azarifar & Shaebanzadeh, 2002; Amir et al., 2008).

Derivatives of pyrazoles have been studied extensively for useful biological effectiveness due to their antiinflammatory, anti-diabetic, anesthetic and analgesic properties (Sarojini et al., 2010; Padhy et al., 2017). In addition, structurally, pyrazole based tridentate ligands have a tendency to bind transition metals in a scorpionate fashion which produces significant number of novel coordination compounds (Lyubartseva & Parkin, 2009; Lyubartseva & Parkin, 2010a; Lyubartseva & Parkin, 2010b; Lyubartseva et al., 2011; Lyubartseva et al., 2012; Lyubartseva et al., 2013a; Lyubartseva et al., 2013b; Lyubartseva et al., 2014; Lyubartseva et al., 2016).

For the past ten years, our research group is continuously studying coordination chemistry of transition metals such as nickel, cobalt and copper to produce new coordination compounds. Cobalt (II) is a $3d^7$ electronic system, which usually results in octahedral, tetrahedral or square planner coordination complexes based on strength of ligands. Typically, weak ligands produce tetrahedral complexes, whereas stronger ligands force octahedral geometry. In this current article, we are describing synthesis, characterization and crystal structure of bis[1-methoxy-2,2,2-tris(pyrazol-1-yl-κN^2) ethane]-cobalt (II) bis-perchlorate as part of our ongoing research efforts.

2. Experimental Procedures

2.1. Materials and Methods

We prepared the ligand, 1-Methoxy-2,2,2-tris(pyrazol-1-yl) ethane (**1**) by following the previously published procedure by Maria and colleagues (Maria et al., 2007). Cobalt (II) perchlorate hexahydrate was purchased from ACROS and used as received. Solvents methanol, acetonitrile and water were used

after being freshly distilled from the bulk. IR data was collected on a Nicolet IR Spectrometer 200. Carbon, hydrogen, and nitrogen content analysis were performed by Robertson Microlit Laboratories.
Caution: Although we did not encounter any problem during our current work, perchlorate salts are potentially explosive and should be handled with great care.

2.2. Synthetic Procedure for bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2) ethane]-cobalt (II) bis-perchlorate

Synthetic scheme for the compound bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2) ethane]-cobalt(II) bisperchlorate **(2)** is shown in Figure 1.

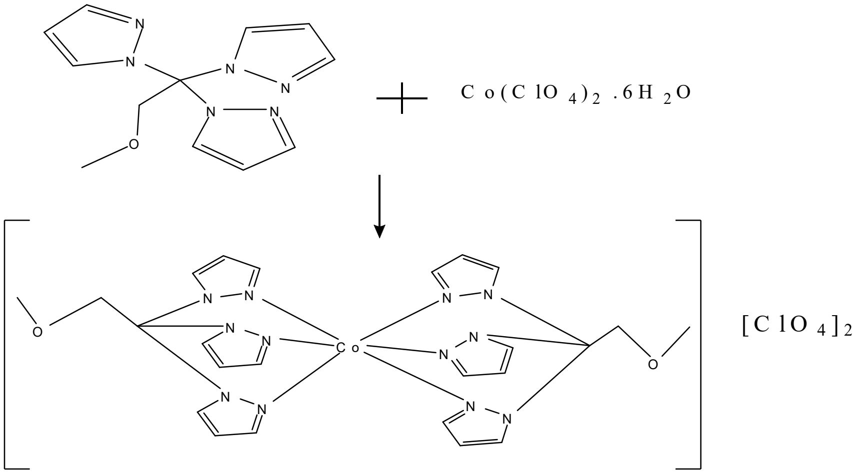

Figure 1. Synthetic scheme for bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2) ethane]-cobalt (II) bisperchlorate.

Cobalt (II) perchlorate hexahydrate (366 mg, 1 mmol) was dissolved in 30 ml freshly distilled methanol at room temperature. In another round bottom flask, 1-methoxy-2,2,2-tris(pyrazol-1-yl) ethane (**1**) (258 mg, 1 mmol) was dissolved in 30 ml freshly distilled methanol at room temperature. Once completely dissolved, the ligand solution was added drop wise to metal solution with moderate stirring. Once the addition was complete, 5 ml of freshly distilled acetonitrile and 10 ml of freshly distilled water were added to the mixture and solution was further stirred for additional 15 minutes. The resulting reaction mixture was gravity filtered, and solvents were slowly evaporated in air. Light yellow color block type crystals were obtained after 2 weeks (413 mg, 53.4% yield). Elemental analysis, calculated for $C_{24}H_{28}N_{12}CoO_{10}Cl_2$: C 37.22, H 3.64, N 21.70; found C 37.18, H 3.51, N 21.58.
IR (cm^{-1}): 3129, 2934, 1636, 1522, 1464, 1411, 1387, 1338, 1319, 1239, 1194, 1143, 1096, 1067, 1015, 978, 954, 917, 856, 782, 759, 659, 636, 618, 609, 593, 417.

2.3. X-Ray Diffraction Data Collection

Compound bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2) ethane]-cobalt (II) bis-perchlorate (**2**) crystallizes as pale-yellow color block crystal with dimensions 0.30 mm X 0.25 mm X 0.17 mm. The crystal was mounted with polyisobutene oil on the tip of a fine glass fiber, which was fastened in a copper mounting pin with electrical solder. It was placed directly into the cold gas stream of a liquid nitrogen-based cryostat, according to published methods (Parkin & Hope, 1998).

Diffraction data were collected with the crystal at 90 K, which is a standard practice in this laboratory for most flash-cooled crystals. X-ray intensity data of the crystal were collected by Nonius KappaCCD X-ray Diffractometer equipped with Mo$K\alpha$ radiation (λ =0.71073Å). The intensities were measured by employing φ and ω scan mode for the diffraction angle at fixed χ = 55°. A total number of 22371 reflections were measured of which 3808 were found to be independent. The criterion ($I > 2\sigma(I)$) was employed to the independent data set and 3117 reflections were treated as observed. The structure was solved by direct methods using SHELXS-97 (Sheldrick, 2008). The final refinement cycles converged to R = 0.040 and $wR(F^2)$ = 0.105 for 3808 observed reflections. Some of the key bond lengths and bond angles, which play an important role in determining the structural properties of this molecule are presented in Table 1.

The view of the molecular structure of the title compound **2**, with atom labeling is shown in Figure 2.

Table 1. Selected bond lengths and bond angles for bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2) ethane]cobalt (II) bis-perchlorate.

Bond Lengths (Å)		Bond Angles (°)	
Co1-N2	2.0937(18)	N2-Co1-N4^i	95.74(7)
Co1-N2^i	2.0937(18)	N2^i-Co1-N4^i	84.26(7)
Co1-N4	2.1096(17)	N2^i-Co1-N4	95.74(7)
Co1-N4^i	2.1096(17)	N2-Co1-N6	83.66(7)
Co1-N6	2.1105(17)	N2^i-Co1-N6	96.34(7)
Co1-N6^i	2.1104(17)	N4^i-Co1-N6^i	82.92(7)

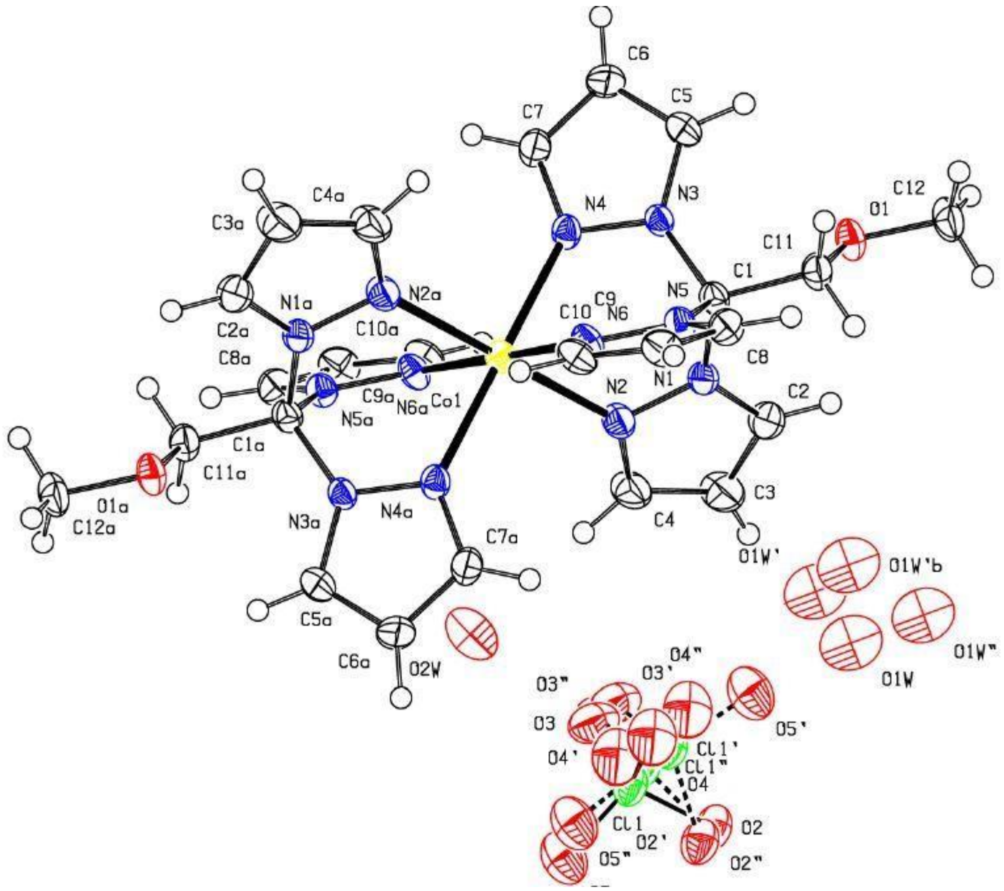

Figure 2. View of molecular structure of bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2) ethane]-cobalt (II) bisperchlorate, with atom labeling. Displacement ellipsoids are drawn at the 50% probability level.

3. Results and Discussion

Treatment of the tripodal scorpionate ligand 1-methoxy-2,2,2-tris(pyrazol-1-yl)ethane (**1**) with commercially available cobalt (II) perchlorate hexahydrate in methanol, acetonitrile and water mixture at 1:1 mole ratio afforded light yellow color block shaped crystal of bis[1-methoxy-2,2,2-tris-(pyrazol-1-yl-κN^2)ethane]-cobalt(II) bis-perchlorate (**2**). All solvents were freshly distilled prior to use in the reaction. The reaction was carried out at room temperature. Slow evaporation of the filtered reaction mixture afforded crystals suitable for X-ray study. Compound **2** crystallizes in the form of light-yellow block crystals in the triclinic space group P1 with unit cell parameters, a = 8.5762(1)Å, b =8.9617(1)Å, c = 11.6820(2) Å, α= 109.7814(7)°, β=93.1681(7)° and γ= 98.1972(7) °. In the crystal, the cobalt (II) ion is coordinated by six nitrogen atoms from two tridentate ligand molecules of ligand 1-methoxy-2,2,2-tris(pyrazol-1-yl) ethane (**1**) with an average cobalt (II)-nitrogen distance of 2.1046 Å. This is a shorter distance compared to the one in the copper (II) complex we published previously (Lyubartseva et al., 2016), where the average copper (II)-nitrogen distance was 2.1224 Å. However, this is a longer distance compared to the analogous distances in two nickel (II) complexes, which we characterized previously, where the average nickel (II)-nitrogen distance were 2.062Å and 2.065 Å correspondingly (Lyubartseva et al., 2013a; Lyubartseva et al., 2013b).

In the title compound, cobalt (II) ion and two ligand molecules form a complex with distorted octahedral geometry. The divalent metal ion is situated in the inversion center. The average nitrogen—cobalt (II)—nitrogen angle between adjacent pyrazole-ring-coordinated nitrogen atoms is 83.6° for the six acute angles and 96.4° for the six obtuse angles. This is very similar to what we observed in previously published complex with copper (II) (Lyubartseva et al., 2016), where the average nitrogen—copper (II)—nitrogen angle between adjacent pyrazole-ring-coordinated nitrogen atoms was 83.7° for the six acute angles and 96.3° for the six obtuse angles. In case of two new compounds with nickel (II) metal, the average nitrogen—nickel (II)—nitrogen angle between adjacent pyrazole-ring-coordinated nitrogen atoms were 84.8°and 85.1° correspondingly for the six acute angles, and 95.2° and 94.9° correspondingly for the six obtuse angles (Lyubartseva et al., 2013a; Lyubartseva et al., 2013b).

In the title complex, intramolecular hydrogen bonds of the nature carbon-hydrogen-oxygen are present between methyl group and oxygen atoms from perchlorate anions. Hydrogen atoms were found in difference Fourier maps, but subsequently included in the refinement using riding models, with constrained distances set to 0.95 Å ($C_{sp2}H$), 0.98 Å (RCH_3) and 0.99 Å (R_2CH_2). U_{iso}(H) parameters were set to values of either 1.2U_{eq} or 1.5U_{eq} (RCH_3 only) of the attached atom.

Although the complex cation species were refined in a very stable manner, the perchlorate anion was significantly disordered. A two-component disorder model for this perchlorate was an improvement, but there were still distinct, albeit small, difference map peaks in a tetrahedral arrangement about the central Cl atom. A third component was added, which further improved the fit. Occupancy factors for the three components were initially refined with a condition that the occupancies sum to 1.0. For the final rounds of refinement, these occupancy factors were held fixed.

In addition to the disordered anion, there were two other prominent features in the difference map. The largest feature was a cluster of ill-defined electron density peaks around the (1/2, 1/2, 1) inversion center. The crystals were grown from a mixture of acetonitrile, water and methanol. Attempts were made to create a disordered solvent model from each of these known solvent species, without success. Complicating the situation further, due to the proximity of the disordered perchlorate, occupancy factors within this disordered solvent region must be correlated with the anion disorder. This in turn precluded the use of SQUEEZE in *PLATON* (Spek, 2009), as it was not possible to separate the disordered solvent and anion electron density. The model here includes three partial occupancy oxygen atoms as a fairly crude attempt to model the density as disordered water molecules. The second prominent difference map feature was a single small blob of electron density, which was modelled as a partial water molecule. Due to the disorder and partial occupancy, water H atoms were not included in the model. No claims are made as to the actual chemical identity of these features. It is for this reason that the moiety and sum formulae are set to match the model, without regard for any solvent hydrogen atoms.

To ensure satisfactory refinement of disordered groups in the structure, a combination of constraints and restraints were employed. The constraints were used to fix overlapping fragments. Restraints were used to maintain the integrity of ill-defined or disordered groups (Parkin, 2000).

4. Conclusion

In this work, we have successfully synthesized and characterized the coordination complex between cobalt (II) metal ion and pyrazole based tridentate ligand 1-methoxy-2,2,2-tris(pyrazol-1-yl) ethane (**1**). Previously, we reported two new coordination complexes with nickel (II) and one new complex with copper (II) metal ions, coordinated with the pyrazole based tripodal scorpionate ligand, 1-methoxy-2,2,2-tris(pyrazol-1-yl) ethane. Based on our synthetic results, we believe that techniques and methods we are utilizing with this ligand in in our research group are reliable and could be further employed in future to produce complexes of other transition metals. This is our fourth successful attempt to synthesize a new compound with this tripodal scorpionate ligand. A growing body of research on pyrazole derivatives indicates the perspective of the future collaboration of our research group with other researchers who study properties of transition metal complexes and their potential applications. Currently, we are investigating chemistry of other transition metals to enrich our dictionary of compounds with this pyrazole based tripodal scorpionate ligand 1-methoxy-2,2,2-tris(pyrazol-1-yl) ethane.

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