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# Coordination Polymers: Bridging Inorganic Chemistry and Materials Science

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## Abstract

Coordination polymers exist at the intersection of inorganic chemistry and materials science. The metal centers and organic ligands are organized into one-, two-, or three-dimensional arrays. Control over their porosity, stability, and reactivity can be achieved through careful modifications of the metal nodes and organic linkers. Recent advancements, including mechanochemical, microwave-assisted, and template-driven methods, have further enhanced the effectiveness of these materials. Their potential applications encompass catalysis, energy storage, sensing, and environmental remediation technologies. However, some challenges remain to be addressed to facilitate their large-scale use in industrial and biomedical sectors. This review not only highlights recent advances in coordination polymers but also presents perspectives for their applications in various fields, contributing to the goal of making these materials green and sustainable.

**Keywords:** Coordination polymers; Metal-organic frameworks; Supramolecular chemistry; Heterogeneous catalysis; Gas sorption; Crystal engineering

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## Introduction

Coordination polymers represent a promising frontier across inorganic chemistry, organic chemistry, and materials science. These versatile materials consist of metal ions or clusters regularly linked by organic ligands to form extended one-, two-, or three-dimensional networks through coordination bonds [Trofimova *et al.*, 2024]. Since the early 1990s, when Robson's pioneering research in this field began, coordination polymers have evolved from mere laboratory curiosities into a vibrant and actively debated area of study with significant applications in catalysis, gas storage, separation techniques, and much more [Lin *et al.*, 2024]. The metal centers provide unique coordination geometries, redox potentials, and Lewis acidities, while the organic ligands contribute structural rigidity, functional groups, and the potential for post-synthetic organic modification [Li *et al.*, 2023]. This inherent modularity enables finely tunable adjustments of pore dimensions, network connectivity, and chemical functionality - levels of structural control rarely achievable with conventional materials [Chen *et al.*, 2025]. Crystallinity and the directional metal-ligand coordination binding structure differentiate Cps from other types of materials. While there are overlaps, with MOFs being a subfamily of CPs that are crystalline and possess permanent porosity alongside robust three-dimensional structures, the scope of CPs extends far beyond this, ranging from one-dimensional chains to two-dimensional sheets that do not conform to the definition of MOFs [He *et al.*, 2023]. This distinction, though often ambiguous in the literature, highlights the rich diversity of structural frameworks made available through coordination chemistry [Hulvey *et al.*, 2024].

The area has expanded dramatically during the last two decades, propelled by remarkable progress in synthetic methodology, characterization tools, and computational modeling. Conventional solvothermal methods have been complemented with new methods, including mechanochemical synthesis, microwave-assisted synthesis, and templating strategies [Zhao *et al.*, 2022], thus expanding the possible chemical space of coordination polymers. Simultaneously, advanced characterization methods, especially in crystallography and spectroscopy, have enriched our understanding of structure-property relationships in these materials [Sun *et al.*, 2022]. The application landscape of coordination polymers covers drug delivery, proton conduction, and energy conversion [Yusuf *et al.*, 2022]. This multifunctional characteristic has positioned coordination polymers as promising platforms for tackling contemporary global energy, environmental challenges, and sustainability [Bieniek *et al.*, 2021]. While a lot of great progress was achieved, still, substantial challenges remain, including increasing the stability of coordination polymers under harsh conditions, scaling of the synthesis for industrial-level applications, and sustainable methods for their preparation and use [Zhou *et al.*, 2023]. To address these challenges, there is a need for cross-disciplinary efforts between synthetic chemists, materials scientists, computational researchers, and engineers [Liu *et al.*, 2020].

In this review, we present an extensive review of coordination polymer chemistry, from fundamental concepts and design strategies to early applications and future potential. Through rigorous scrutiny of emerging trends and enduring challenges, we aspire to provide newcomers and established scholars alike with a welcome guide to navigate this vibrant and influential area.

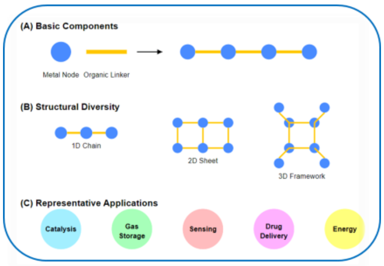

Figure 1: Schematic representation of coordination polymer construction and classification. (A) Basic components: metal nodes and organic linkers assemble through coordination bonds. (B) Structural diversity: formation of 1D chains, 2D sheets, and 3D frameworks through varying connectivity. (C) Representative applications across multiple domains, including catalysis, gas storage, sensing, and drug delivery.

The rational design of coordination polymers (CPs) is fundamental to crystal engineering, facilitating the precise adjustment of structural and functional characteristics by meticulously choosing metal centers and organic linkers during controlled synthesis conditions [James, 2003]. These materials arise from combining metal nodes and multidentate ligands, forming extended frameworks through coordination bonds [Rosi *et al.*, 2003]. Metal centers play a critical role in directing framework architecture, with coordination geometry determining the dimensionality and directionality of growth. Transition metals exhibit versatile geometries—octahedral ($Fe^{3+}$, $Cr^{3+}$), square planar ($Pd^{2+}$, $Pt^{2+}$), tetrahedral ($Zn^{2+}$, $Co^{2+}$), and linear ($Ag^{+}$, $Au^{+}$)—depending on their electronic and steric characteristics [Corma *et al.*, 2010]. Lanthanides have large ionic radii and coordination numbers, and when combined in a large array, they offer complex lattices with unusual magnetic and luminescent behaviours [Wang *et al.*, 2020]. The oxidation state of the metal ion affects the electronic structure and Lewis acidity, as well as the stability of the framework in general [Kitagawa *et al.*, 1999]. Carboxylate, 5-pyridyl, phosphonate, cyano-containing, and other ligands offer different coordination and connectivity modes [Rowsell and Yaghi, 2004]. The topology of the network is dictated by the geometric properties of ligands (rigidity, angularity, and symmetry) [Gándara *et al.*, 2014]. The incorporation of the functional groups within the ligands allows for adaptable features, including selectivity, catalytic activity, and external stimuli responsiveness [Yang *et al.*, 2021].

The "node-and-spacer" model has been used as a basis for understanding crystal engineering, in which metal ions play the role of directionality nodes and organic linkers act as spacers to control the organization in space [Batten *et al.*, 2009]. The use of secondary building units (SBUs), like metal–oxo clusters or paddlewheel motifs, introduces predictability and modular design [Férey *et al.*, 2005]. In addition, non-covalent interactions such as hydrogen bonding, π–π interaction, and van der Waals force have had a remarkable impact on the packing of the framework and the encapsulation behavior of the guest [MacGillivray, 2004]. Topological analysis— the approach to describe CPs with graph theory specifications based on node-and-linker networks can be used to classify frameworks in terms of known topologies such as diamond, pcu, or NbO types, and therefore to systematically investigate and rationalize structural diversity [Blatov *et al*., 2014]. These guiding rules have transformed CP synthesis from one of empirical inquiry to a synthetic design approach, with which researchers design structure-function relationships for next-generation applications in catalysis, gas separation, energy storage, and sensing [Li *et al*., 1999].

## Structural Characterization Techniques

The determination of the structures of simply structured coordination polymers, from the molecular to large length scales, is a precursor for the development of structure–property relationships and for guidance in the design of new materials [Cheetham *et al*., 2006]. Current structural characterization methods integrate complementary methods to give a complete picture of structure spanning from atomic connectivity to mesoscale organization [Rowsell *et al*., 2004].

### 2.1 X-ray Diffraction Methods

X-ray diffraction methods are still a gold standard in studying coordination polymers from which coordinates of atomic positions, as well as bond parameters, can be extracted, and further, the 3D architecture is obtained. Single-crystal X-ray diffraction (SCXRD) provides the ultimate structural resolution when crystals can be grown, and intramolecular and intermolecular coordination environments, ligand conformations, and arrangement of guest molecules can be determined with high precision [Willems *et al*., 2012]. In a related development, extremely high surface area frameworks with gigantic unit cells can now be analyzed thanks to recent improvements in synchrotron radiation [Farha *et al*., 2012]. The Rietveld method can provide reliable structural information, as has been demonstrated in the characterization of MIL-series frameworks [Serre *et al*., 2002]. PDF analysis extends the capabilities to amorphous or nanocrystalline CPs, which retain the short-range order [Chapman *et al*., 2009]. In situ and operando XRD methods now allow the tracking of structural changes during guest adsorption, catalysis, or phase transitions [Tan *et al*., 2010]. Kitagawa and co-workers used in situ techniques to reveal dynamic gate-opening behavior in flexible frameworks [Uemura *et al*., 2006]. Variable-temperature XRD provides insights into thermal responses such as spin crossover and negative thermal expansion [Ohba *et al*., 2009].

### 2.2 Spectroscopic Methods

Spectroscopy is a natural parallel to diffraction because the two methods probe chemical bonding and local environment. Both IR and Raman spectroscopy are sensitive to the vibrational motion of metal–ligand bonds and guest interactions, whereas far-IR bands confirm coordination modes [Zhao *et al*., 2018]. Recently, the ssNMR has proved to be a sensitive technique for the characterization of CPs, particularly for disordered systems. Martineau-Corcos *et al*. showed that structural dynamics were revealed by a multinuclear ssNMR [Martineau-Corcos *et al*., 2012]. X-ray absorption spectroscopy (XAS) measurement, including XANES and EXAFS, offers a detailed metal-centered view in terms of oxidation state and coordination environments, including mixed-metal or amorphous materials [Dincă and Long, 2007].

### 2.3 Microscopy Techniques

Microscopy offers an avenue of morphological and nanoscale structural information. The particle morphology, crystal habit, and hierarchical structure are shown by scanning electron microscope (SEM) and transmission electron microscope (TEM) [Liu *et al*., 2014]. The recent development of low-dose TEM has allowed atomic resolution imaging of defects in MOFs [Zhu and Xu, 2014]. AFM (atomic force microscopy) was used to characterize surface topography and mechanical properties at a nanometre scale [Roodenko *et al*., 2015].

### 2.4 Computational Approaches

Characterization is facilitated with computational tools that simulate structures, spectra, and dynamics. Structural optimization and electronic and vibrational properties can be calculated using density functional theory (DFT) [Valenzano *et al*., 2011]. Here, machine learning and automated analysis now drive the solution and interpretation of structure, as demonstrated in recent work from Snurr and co-workers [Rosen *et al*., 2021].

### 2.5Integrated Characterization Strategies

Integrated ones provide multi-dimensional viewpoints for CPs. Coupled diffraction–spectroscopy methods connect the average and local structure [Goesten *et al*., 2013]. Very precise analysis of framework stability, decomposition, and guest release is guaranteed by the simultaneous TGA-MS, or TGA-IR [Loiseau *et al*., 2006]. The developments in characterization techniques, coupled with advances in resolution, sensitivity, and data processing, will further deepen the understanding of coordinating polymers by facilitating clear structure–activity relationships.

## 3.Applications of Coordination Polymers

Coordination Polymers (CPs) based on metal ions/bonds with the coordination polymerization between metal ions and multidentate (also called polydentate) N, O, or S ligand building blocks have been explored toward all sorts of patterns and structures. In gas storage, their holes can trap carbon dioxide, hydrogen, and methane. Their tunable active sites provide advantages for catalysis. They are ideal for chemical sensing due to the modulation of optical properties upon guest molecule binding. In drug delivery, they can transport and release drugs. They have semiconducting properties and can be used in electronic or photovoltaic applications. Magnetism has also been explored in coordination polymers, with some showing odd magnetic behavior. Their stability and processability have been greatly improved in recent years, which extends their potential applications in water purifications, luminescent materials, biomedicine, etc. Various applications of coordination polymers have been shown in Figure 2.

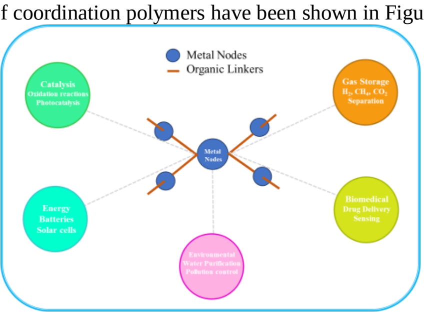

Figure 2. Various applications of coordination polymers

### 3.1 Applications in Catalysis

Coordination polymers: from minerals to heterogeneous catalysis

Coordination polymers (CPs) are an emerging class of materials with important applications in heterogeneous catalysis. Constructed from metal ions or clusters connected by organic ligands, these materials present a special combination of flexibility of structure and controllable properties, which makes them an excellent catalytic platform [Furukawa *et al*., 2013]. Due to their structural regularity, large surface area, and tunable chemical environment, they have been intensively studied in many catalytic reactions [Lee *et al*., 2009]. These materials bridge homogeneous and heterogeneous catalysis, bringing the well-defined active sites of molecular catalysts together and at the same time conferring on them the recyclability and stability of heterogeneous catalysts [Dhakshinamoorthy *et al*., 2012]. As for the members of the group of MOFs, the metal nodes could act as Lewis-type acid sites while the organic linkers could be functionalized to incorporate specific catalytic groups [Ma *et al*., 2009]. A porous structure permits mass transport and size-selective catalytic action, making these materials molecular sieves that behave as catalysts [Férey, 2008]. Coordination polymers have also shown excellent performance as peroxidase-like oxidation agents across the reactions. Copper and iron MOFs are also efficient catalysts for the oxidation of alcohols, sulfides, and hydrocarbons at mild reaction conditions [Corma *et al*., 2010]. For instance, Cu-BTC (HKUST-1) has been reported to be highly efficient in the oxidation of benzyl alcohol to benzaldehyde with molecular oxygen as oxidant [Dhakshinamoorthy and Garcia, 2014]. The isolated metal centers in the matrix containing open, active sites, coupled with the porous nature, facilitate the reaction: oxygen diffusion and lead to highly efficient conversion of reactants and products [Xiao *et al*., 2017]. These materials can absorb light either via ligand-to-metal charge transfer (LMCT) or metal-to-ligand charge transfer (MLCT) transitions, and thus produce excited states which can drive redox reactions [Sun *et al*., 2015]. The group of titanium MOFs has been used for photocatalytic hydrogen evolution as well as photocatalytic CO2 reduction [Wang *et al*., 2011], and ruthenium and iridium MOFs have been exploited for visible-light-driven organic transformations [Zhou *et al*., 2014]. When chiral ligands or building blocks are introduced, these materials introduce the so-called asymmetric environments at their catalytic centers, which could lead to enantioselective transformations [Seo *et al*., 2000]. This has been successfully applied for the preparation of optically active compounds in the asymmetric hydrogenation, epoxidation, and cycloaddition reactions [Cho *et al*., 2010], which provides a way to produce optically pure compounds with heterogeneous catalysts [Buru *et al*., 2018]. Amassing ahead, the combination of CPs with other materials, including graphene [Wu *et al*., 2012], metal nanoparticles, and enzymes, etc., can produce hybrid catalysts further boosting catalytic performance and enlarging the applications. As well, stimuli-responsive coordination polymers have been developed to dynamically manipulate the catalysis activity via an external stimulus (such as light, temperature, or chemical trigger) [Coudert, 2015]. Although industrialization of coordination polymer in some of those areas is not yet widespread, in fine chemical synthesis, environmental pollution control, and energy conversion, the results of pilot-scale tests in the actual production lines have indicated their applicability [Chughtai *et al*., 2015]. The scalable production of these materials, combined with their exceptional catalytic properties, positions them as promising candidates for next-generation industrial catalysts [Gascon *et al*., 2014].

### 3.2 Gas Storage and Separation Applications

Coordination polymers, especially metal-organic frameworks (MOFs), have brought a big leap to the field of gas storage and separation because of their outstanding porosity, tailored pore structure, and versatile chemical functionality [Li *et al*., 2009]. These substances possess exceptional surface areas—often greater than 7000 $m^2/g$—thereby making them promising candidates for gas-based applications [Farha *et al*., 2012].Coordination polymers in the storage of GAs. In the area of gas storage, CPs are good adsorbents for large quantities of industrially and environmentally important gases [Murray *et al*., 2009]. MOFs: storage materials for hydrogen and methane Metal–organic framework (MOF) materials have attracted increasing interest as potential hydrogen storage materials for clean energy storage, with materials such as MOF-5 and HKUST-1 showing good promise of high gravimetric uptake capacity at cryogenic temperatures [Bae and Snurr, 2011]. For storage of the most common natural gas (methane), it provides a less risky alternative to pressure vessels, where compounds like IRMOF-6 and PCN-14 have demonstrated unprecedented ADMs that would be in line with DoE targets for vehicular applications [Herm *et al*., 2014]. Another important application is the capture of carbon dioxide, as well as providing a tool for climate change. Amine-terminated MOFs, such as MIL-101(Cr)-$NH_2$, show high affinity of $CO_2$ via acid-base interactions [Sumida *et al*., 2012], and open metal sites in Mg-MOF-74 have an outstanding adsorption selectivity for $CO_2$ concerning other gases [Caskey *et al*., 2008]. Certain frameworks can even capture $CO_2$ under water-saturated conditions, which is a major hurdle in postcombustion carbon capture [Lin *et al*., 2015]. Concerning gas separation, COF could provide for molecular sieving mechanism and have extensive applications, including molecular sieving via size exclusion, selective adsorption driven by thermodynamic interaction [Li *et al*., 2016]. ZIF-8 has exhibited good separation of propane/propylene mixtures by size exclusion [Banerjee *et al*., 2008], and Cu-BTC has been shown to selectively adsorb $CO_2/CH_4$ mixtures due to preferential binding of $CO_2$ [Wang *et al*., 2016]. Flexible or "breathing" MOFs like MIL-53 exhibit stimuli-responsive behavior, changing their pore dimensions upon gas adsorption and providing unique separation capabilities [Serre *et al*., 2002].

In the industrial field, if the use of coordination polymers for gas applications is still in development, some commercial products are now available [Mason *et al*., 2014]. Scale-up production, mechanical stability, and hydrolytic resistance are systematically tackled via composite and chemical modifications [Burtch *et al*., 2014], thus allowing larger-scale practical utilization in energy storage, environmental remediation, and industrial separation processes [Yang *et al*., 2017].

### 3.3 Energy-Related Applications

Coordination polymers (CPs) are a class of versatile materials that have been attracting extensive attention in various energy fields. Due to their modifiable designs, structural variances, and adjustable properties, they have been considered as a versatile technology to solve environmental and energy problems [Li *et al*., 2016]. In energy storage, coordination polymers have also been investigated as electrode materials for batteries and supercapacitors. Cobalt- and nickel-based MOFs were found to be very promising candidates for cathodes in lithium-ion batteries, with high capacities and good cyclic stabilities [Xia *et al*., 2015]. Some as-synthesized coordination polymers are also applied as carbon-containing electrode materials, and the controlled pyrolysis of them under an appropriate temperature could obtain nanostructured carbons with improved conductivity and surface area but original morphology [Zhao *et al*., 2018]. The materials with earth-abundant metals such as cobalt, iron, and nickel performed similar catalytic activity to the precious metal catalysts, with ease of availability and low cost [Sun *et al*., 2016]. The structural tunability can provide an accurate placement of the catalytic sites and can optimize the electronic properties [Wang *et al*., 2017]. Zirconium MOFs have been introduced in dye-sensitized solar cells, and they serve as hosts for photosensitizers and are also conducive to the diffusion of the electrolyte through their pores [Ji *et al*., 2020]. Some coordination polymers are semiconductors themselves with band gaps in the visible light region, which can facilitate direct photocatalysis without the need for sensitizers [Hu *et al*., 2014]. The carbon materials derived from coordination polymer-supported platinum nanoparticles have been reported to be more active for the oxygen reduction reaction in protonic exchange membrane fuel cells [Zhang *et al*., 2018]. Phosphonate-based coordination polymers also show impressive proton conductivity at anhydrous state, which is a major drawback associated with high-temperature fuel cell operation [Ramaswamy *et al*., 2014]. The possibility of separately tailoring the electrical and the thermal transport characteristics via the choice of the metal and the ligand is also unique and facilitates maximizing the thermoelectric figure of merit [Usman *et al*., 2020]. When used on adsorption heating and cooling systems, it provides an energy-efficient alternative to the compression technologies [Burtch *et al*., 2014]. The combined systems of CPOSs and other functional materials result in synergic composites with improved properties. The MOF/graphene composites possess high SSA of MOF and excellent conductivity of graphene, which are beneficial to overcome the intrinsic conductivity limitation in most of the CPs [Zhang *et al*., 2014]. With ongoing research, the issues surrounding the stability, conductivity, and large-scale production, where applicable, are being systematically solved, reducing the gap between the lab and practical application of coordination polymer-based energy technologies. Their ongoing development offers great prospects for sustainable energy solutions in various technological areas [Wang *et al*., 2008].

### 3.4 Sensing and Biomedical Applications

Coordination polymers have been and continue to be excellent platforms for sensing and biomedicine because of their structural diversity, adjustable functionalities, and special responses. There are innovative uses in a wide range of healthcare diagnostics, therapeutics, and environmental monitoring [Cui *et al*., 2012]. Luminescent MOFs (LMOFs) are especially useful because the analyte's presence can be detected by different mechanisms, including guest-induced ligand-to-metal charge transfer, competitive binding, or sensitization processes [Allendorf *et al*., 2009]. The lanthanide coordination polymers have characteristic sharp emission bands and long luminescence lifetimes, which make them suitable for the detection of substances, including volatile organic compounds and heavy metal ions [Wang *et al*., 2013]. MOF-encapsulated enzymes exhibit biocatalytic activities and protect enzymes from denaturation, thus prolonging the lifetime of sensors [Chen *et al*., 2012]. Targeting ligands-functionalized coordination polymers for selective detection of cancer biomarkers, pathogens, and metabolites exist in complex biological fluids [Zhuang *et al*., 2014]. As delivery vehicles, they have a porous structure to house the therapeutic payloads, and surface chemistry can be tailored for targeted delivery [Horcajada *et al*., 2010]. Controlled drug delivery may be directed using a variety of stimuli, such as a change in pH, redox state, or light exposure, allowing both temporal and spatial control over drug release profiles [Simon-Yarza *et al*., 2016]. Materials that, for example, incorporate paramagnetic metal ions pr serve as contrast agents for MRI, while their luminescent variants enable high-resolution optical imaging [Chen *et al*., 2020]. Both capabilities are provided by multimodal imaging platforms, which use a single agent but provide complementary diagnostic information [Wang *et al*., 2020]. These materials can cause the sustained elution of metal ions, which provides prolonged antimicrobial activity while still maintaining low systemic toxicity [He *et al*., 2014]. Medical devices and implants coated with MOFs mitigate biofilm formation and decrease healthcare-associated infection risk [Wyszogrodzka *et al*., 2016]. In tissue engineering, scaffolds made with coordination polymers also serve as mechanical supports while delivering growth factors and other bioactive molecules to enhance tissue regeneration. They can be designed to degrade at the same rate as new tissue formation, allowing smooth integration with the host tissue [Munnuri *et al*., 2020]. To address these concerns, the focus of recent progress shifted to biodegradable coordination polymers made of biocompatible ligands and endogenous metals [Li *et al*., 2021]. Figure 3 depicts the coordination polymer in sensing and biomedical applications.

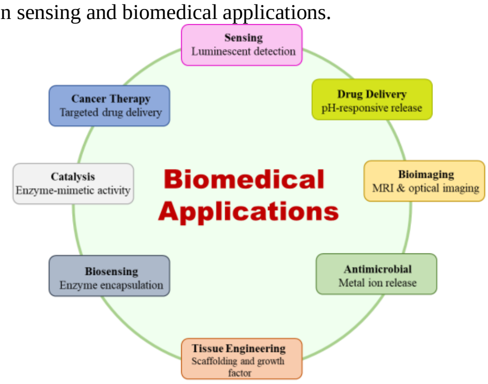

Figure 3. Coordination Polymer in sensing and biomedical applications.

The combination of coordination polymers with biological elements such as proteins, nucleic acids, and cells is furthering their biomedical application. Such hybrid materials exhibit the structural accuracy offered by synthetic chemistry alongside the advanced functions of biological systems, thus paving the way for more advanced personalized medicine, diagnostics, and regenerative therapies [Farha & Hupp, 2010].

### 3.5 Environmental Applications

Due to their unique structural adaptability and programmable physicochemical properties, coordination polymers have attracted attention as advanced materials to solve critical environmental problems. These materials provide transformative approaches in various areas of the environment, such as water and air purification and pollutant detection [Kundu *et al*., 2016]. In the classification of water treatment processes, the capabilities of coordination polymers are remarkable in the removal of heavy metal pollutants through mechanisms of ion exchange, adsorption to the surface, and chelation via coordination bonds. The presence of carboxylate, phosphonate, or thiol functional groups is known for their strong binding to toxic metals like lead, mercury, and cadmium, achieving removal rates above 95% even at low concentrations [Cui *et al*., 2012]. Such adsorbents can be regenerated by adjusting pH or by competitive ion displacement and used repeatedly over multiple treatment cycles [Gong *et al*., 2019]. Coordination polymers provide functionalized frameworks for the adsorption of pharmaceutical effluents, industrial dyes, and other organic pollutants by incorporating specific capture sites designed to enhance binding. Some frameworks contain hydrophobic cavities that capture aromatic compounds through π-π interactions, while others with Lewis acidic metal sites bind strongly to electron-rich contaminants [Wang *et al*., 2019a].

Some coordination polymers even exhibit catalytic properties and degrade pollutants rather than simply capturing them [Wang *et al*., 2019b]. Amine-functionalized frameworks are especially effective for carbon dioxide capture from industrial emissions [Sumida *et al*., 2012], while those with open metal sites can adsorb formaldehyde and other indoor air pollutants at room temperature [McDonald *et al*., 2011]. As environmental sensors, luminescent coordination polymers enable rapid, visual detection of dangerous substances. The intensity of luminescence often increases with the concentration level of the contaminant, allowing for advanced quantitative measurement without complex equipment—a huge advantage for field use in resource-poor areas [Xie *et al*., 2020]. Coordination polymers that are water-stable and made from inexpensive metals alongside bio-sourced ligands mark dramatic strides toward practical environmental use [James, 2003]. These materials, which have been developed in labs, still require additional research integration with existing environmental treatment technologies and adaptation to changing environmental conditions [Trickett *et al*., 2017].

## Future Directions and Conclusion

In recent times, coordination polymers (CPs) have evolved as a handy material that has multifunctional properties and whose structures can be altered very easily. This makes them a valuable material in diverse applications that include catalysis, gas storage, energy devices, biosensors, and environmental remedy. Several challenges must be tackled if we want to take full use of the coordination polymers for the development in the interest of science. One of the most important key developments is the increments in the stimuli-responsive or smart CPs that can effectively make changes in the responses to temperature, pH, light, or electric fields. These dynamic properties make them suitable for their usage in sensing, drug delivery, and adaptive catalysis. Their capability can be enhanced by integrating them with other materials such as graphene, nanoparticles, which results in to hybrid material with synergistic properties for innovative electronic applications. One more key is the development in the computational and machine learning-aided inventions of CPs. The resulting predictive models can perform the screening of various specific properties, which leads to more efficient, rational design. The biomedical applications are expanding day by day, but their toxicity, biodegradability are the important points that one needs to keep in mind. Green and sustainable synthesis of the coordination polymers is becoming very popular in recent times, which focuses on the use of environmentally benign solvents, low-energy pathways, and ecological materials.

Coordination polymers are present at the juncture of the two important fields of science, i.e., inorganic chemistry and material chemistry, that combine and provide a unique platform for the invention across various scientific fields. As with the growing research, interdisciplinary experimental approaches, which include synthetic chemistry, computational chemistry, and innovative characterization tools, will be very pivotal for taking full advantage of Coordination polymers. The dependency of future evolution will not be only on scientific resourcefulness but also on sustainable practices and practical applicability. Safeguarding these materials contributes eloquently to societal and scientific developments.

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