

# Inorganic Chemistry and Associated Perspectives in Real Domains and Applications

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## **Abstract**

An inorganic compound is typically a chemical compound that lacks carbon–hydrogen bonds, that is, a compound that is not an organic compound. However, the distinction is not clearly defined and agreed upon, and authorities have differing views on the subject. Inorganic compounds comprise most of the Earth's crust, although the compositions of the deep mantle remain active areas of investigation. Some simple compounds that contain carbon are often considered inorganic. Examples include carbon monoxide, carbon dioxide, carbonates, carbides, cyanides, cyanates, and thiocyanates. Many of these are normal parts of mostly organic systems, including organisms; describing a chemical as inorganic does not necessarily mean that it does not occur within living things.

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## Introduction

Inorganic synthetic methods can be classified roughly according to the volatility or solubility of the component reactants. Soluble inorganic compounds are prepared using methods of organic synthesis. For metal-containing compounds that are reactive toward air, Schlenk line and glove box techniques are followed. Volatile compounds and gases are manipulated in “vacuum manifolds” consisting of glass piping interconnected through valves, the entirety of which can be evacuated to 0.001 mm Hg or less. Compounds are condensed using liquid nitrogen (b.p. 78K) or other cryogenics. Solids are typically prepared using tube furnaces, the reactants and products being sealed in containers, often made of fused silica (amorphous SiO<sub>2</sub>) but sometimes more specialized materials such as welded Ta tubes or Pt “boats”. Products and reactants are transported between temperature zones to drive reactions.

An alternative perspective on the area of inorganic chemistry begins with the Bohr model of the atom and, using the tools and models of theoretical chemistry and computational chemistry, expands into bonding in simple and then more complex molecules. Precise quantum mechanical descriptions for multielectron species, the province of inorganic chemistry, is difficult. This challenge has spawned many semi-quantitative or semi-empirical approaches including molecular orbital theory and ligand field theory, In parallel with these theoretical descriptions, approximate methodologies are employed, including density functional theory.

Exceptions to theories, qualitative and quantitative, are extremely important in the development of the field. For example, Cu<sup>II</sup><sub>2</sub>(OAc)<sub>4</sub>(H<sub>2</sub>O)<sub>2</sub> is almost diamagnetic below room temperature whereas Crystal Field Theory predicts that the molecule would have two unpaired electrons. The disagreement between qualitative theory (paramagnetic) and observation (diamagnetic) led to the development of models for "magnetic coupling." These improved models led to the development of new magnetic materials and new technologies.

Inorganic chemistry, the study of all the elements and their compounds with the exception of carbon and its compounds, which fall under the category of organic chemistry. Inorganic chemistry investigates the characteristics of substances that are not organic, such as nonliving matter and minerals found in the earth's crust. Branches of inorganic chemistry include applications in organic chemistry, bioinorganic chemistry, coordination chemistry, geochemistry, inorganic technology, nuclear science and energy, organometallic compounds, reaction kinetics and mechanisms, solid-state chemistry, and synthetic inorganic chemistry.

Inorganic chemistry pursues molecular and materials science with the whole periodic table as its domain. Transition metal-catalyzed reactions account for an economic output that equals the GDP of most industrialized nations. Green chemistry seeks to make these processes more efficient. As we strive towards a more sustainable future, inorganic compounds are likely to play a key role in development of large scale alternative energy sources. Meanwhile, nature is a fabulous inorganic chemist: some enzymes and regulatory proteins contain metal centers that control both chemical transformations and protein architecture. Materials and nanochemistry are other burgeoning branches of inorganic chemistry that promise advances in communications, data storage, sensing, and catalysis.

The inorganic chemistry group at research labs focuses on organometallic and coordination chemistry, bioinorganic chemistry, materials chemistry and catalysis. Reaction mechanisms, new chemical transformations, and novel structures, bonding, and electronic states lie at the heart of these areas. At Yale, one might investigate the catalytic properties of a new material; the mechanism of an organometallic reaction; the interaction of organic and metal-based radicals with the core of a photosynthetic site; the nature of proton coupled electron transfer in nanoparticles; the mechanism of action of a metalloenzyme; the design of a new catalyst; organometallic methods development in organic synthesis; or a green synthesis for a pharmaceutical.

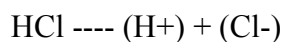
In general, substances of mineral origin (such as ceramics, metals, synthetic plastics, as well as water) as opposed to those of biological or botanical origin (such as crude oil, coal, wood, as well as food). With certain exceptions, inorganic substances do not contain carbon or its compounds.

There are around 100,000 known inorganic compounds, while there are around two million known organic compounds. Examples of inorganic compounds include:

- Sodium chloride (NaCl): used as table salt
- Silicon dioxide (SiO<sub>2</sub>): used in computer chips and solar cells
- Sapphire (Al<sub>2</sub>O<sub>3</sub>): a well-known gemstone
- Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>): a chemical widely used in the production of fertilizers and some household products such as drain cleaners

Inorganic compounds can be classified as acids, bases, salts, and oxides. Let's talk about them in a little more detail:

**Acids:** Acids are compounds that produce H<sup>+</sup> ions when dissolved in water. Examples of acids include sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), hydrochloric acid (HCl), hydrofluoric acid (HF), acetic acid or vinegar (HC<sub>2</sub>H<sub>3</sub>O<sub>2</sub>), and citric acid (C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>). Most acids can be dissolved in water and are corrosive, and those that can be ingested have a sour taste. In water, HCl is decomposed in H<sup>+</sup> and Cl<sup>-</sup>



**Bases:** Bases are compounds that produce OH<sup>-</sup> (hydroxyl ions) when dissolved in water. They are usually found in household products. Some common bases are ammonia (NH<sub>3</sub>), potassium hydroxide (KOH), calcium hydroxide or caustic lime (Ca(OH)<sub>2</sub>), and sodium hydroxide or caustic soda (NaOH). In water, KOH dissociates in K<sup>+</sup> and OH<sup>-</sup> :

KOH ---- (K<sup>+</sup>) + (OH<sup>-</sup>)

**Salts:** Salts are compounds that result from the reaction between an acid and a base. They are ionic compounds formed by two oppositely charged ions (atoms that are not electrically neutral because they have lost or gained one or more electrons). For example, table salt or sodium chloride (NaCl) is formed by the bonding an anion (positively charged ion) and a cation (negatively charged ion): Na<sup>+</sup> and Cl<sup>-</sup>.

Some common salts include sodium chloride or table salt (NaCl), calcium chloride (CaCl<sub>2</sub>), magnesium chloride (MgCl<sub>2</sub>), and potassium chloride (KCl). Most salts can be dissolved in water to form a solution of the ions. Ions derived from salts like Na<sup>+</sup>, Mg<sup>+2</sup>, and K<sup>+</sup> are critical for the functioning of the human body. In water, CaCl<sub>2</sub> is decomposed in the following way:  
CaCl<sub>2</sub> ----- (Ca<sup>+2</sup>) + (Cl<sup>-</sup>)

Oxides are compounds that contain at least one oxygen atom combined with another element. Oxygen is usually in the form of an anion (O<sup>2-</sup>). Transition metal oxides such as titanium (III) oxide (Ti<sub>2</sub>O<sub>3</sub>) and iron (III) oxide (Fe<sub>2</sub>O<sub>3</sub>) have useful magnetic and catalytic properties. Let's go over some examples of reactions.

Inorganic chemistry deals with synthesis and behavior of inorganic and organometallic compounds. This field covers all chemical compounds except the myriad of organic compounds (carbon-based compounds, usually containing C-H bonds), which are the subjects of organic chemistry. The distinction between the two disciplines is far from absolute, as there is much overlap in the subdiscipline of organometallic chemistry. It has applications in every aspect of the chemical industry, including catalysis, materials science, pigments, surfactants, coatings, medications, fuels, and agriculture.

Many inorganic compounds are ionic compounds, consisting of cations and anions joined by ionic bonding. Examples of salts (which are ionic compounds) are magnesium chloride  $MgCl_2$ , which consists of magnesium cations  $Mg^{2+}$  and chloride anions  $Cl^-$ ; or sodium oxide  $Na_2O$ , which consists of sodium cations  $Na^+$  and oxide anions  $O^{2-}$ . In any salt, the proportions of the ions are such that the electric charges cancel out, so that the bulk compound is electrically neutral. The ions are described by their oxidation state and their ease of formation can be inferred from the ionization potential (for cations) or from the electron affinity (anions) of the parent elements.

Important classes of inorganic compounds are the oxides, the carbonates, the sulfates, and the halides. Many inorganic compounds are characterized by high melting points. Inorganic salts typically are poor conductors in the solid state. Other important features include their high melting point and ease of crystallization. Where some salts (e.g.,  $NaCl$ ) are very soluble in water, others (e.g.,  $FeS$ ) are not.

The simplest inorganic reaction is double displacement when in mixing of two salts the ions are swapped without a change in oxidation state. In redox reactions one reactant, the oxidant, lowers its oxidation state and another reactant, the reductant, has its oxidation state increased. The net result is an exchange of electrons. Electron exchange can occur indirectly as well, e.g., in batteries, a key concept in electrochemistry.

When one reactant contains hydrogen atoms, a reaction can take place by exchanging protons in acid-base chemistry. In a more general definition, any chemical species capable of binding to electron pairs is called a Lewis acid; conversely any molecule that tends to donate an electron pair is referred to as a Lewis base. As a refinement of acid-base interactions, the HSAB theory takes into account polarizability and size of ions.

Inorganic compounds are found in nature as minerals. Soil may contain iron sulfide as pyrite or calcium sulfate as gypsum. Inorganic compounds are also found multitasking as biomolecules: as electrolytes (sodium chloride), in energy storage (ATP) or in construction (the polyphosphate backbone in DNA).

The first important man-made inorganic compound was ammonium nitrate for soil fertilization through the Haber process. Inorganic compounds are synthesized for use as catalysts such as vanadium(V) oxide and titanium(III) chloride, or as reagents in organic chemistry such as lithium aluminium hydride.

Subdivisions of inorganic chemistry are organometallic chemistry, cluster chemistry and bioinorganic chemistry. These fields are active areas of research in inorganic chemistry, aimed toward new catalysts, superconductors, and therapies.

#### Industrial inorganic chemistry

Inorganic chemistry is a highly practical area of science. Traditionally, the scale of a nation's economy could be evaluated by their productivity of sulfuric acid. The top 20 inorganic chemicals manufactured in Canada, China, Europe, India, Japan, and the US (2005 data): Aluminium sulfate, Ammonia, Ammonium nitrate, Ammonium sulfate, Carbon black, Chlorine, hydrochloric acid, hydrogen, hydrogen peroxide, nitric acid, nitrogen, oxygen, phosphoric acid, sodium carbonate, sodium chlorate, sodium hydroxide, sodium silicate, sodium sulfate, sulfuric acid, and titanium dioxide. The manufacturing of fertilizers is another practical application of industrial inorganic chemistry.

#### Descriptive inorganic chemistry

Descriptive inorganic chemistry focuses on the classification of compounds based on their properties. Partly the classification focuses on the position in the periodic table of the heaviest

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element (the element with the highest atomic weight) in the compound, partly by grouping compounds by their structural similarities.

Classifications of inorganic chemistry:

EDTA chelates an octahedrally coordinated  $\text{Co}^{3+}$  ion in  $[\text{Co}(\text{EDTA})]^-$ . Classical coordination compounds feature metals bound to "lone pairs" of electrons residing on the main group atoms of ligands such as  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ ,  $\text{Cl}^-$ , and  $\text{CN}^-$ . In modern coordination compounds almost all organic and inorganic compounds can be used as ligands. The "metal" usually is a metal from the groups 3-13, as well as the trans-lanthanides and trans-actinides, but from a certain perspective, all chemical compounds can be described as coordination complexes.

The stereochemistry of coordination complexes can be quite rich, as hinted at by Werner's separation of two enantiomers of  $[\text{Co}((\text{OH})_2\text{Co}(\text{NH}_3)_4)_3]^{6+}$ , an early demonstration that chirality is not inherent to organic compounds. A topical theme within this specialization is supramolecular coordination chemistry. Examples:  $[\text{Co}(\text{EDTA})]^-$ ,  $[\text{Co}(\text{NH}_3)_6]^{3+}$ ,  $\text{TiCl}_4(\text{THF})_2$ .

Tetrasulfur tetranitride,  $\text{S}_4\text{N}_4$ , is a main group compound that continues to intrigue chemists

These species feature elements from groups I, II, III, IV, V, VI, VII, 0 (excluding hydrogen) of the periodic table. Due to their often similar reactivity, the elements in group 3 (Sc, Y, and La) and group 12 (Zn, Cd, and Hg) are also generally included, and the lanthanides and actinides are sometimes included as well

Compounds containing metals from group 4 to 11 are considered transition metal compounds. Compounds with a metal from group 3 or 12 are sometimes also incorporated into this group, but also often classified as main group compounds.



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Transition metal compounds show a rich coordination chemistry, varying from tetrahedral for titanium (e.g.,  $\text{TiCl}_4$ ) to square planar for some nickel complexes to octahedral for coordination complexes of cobalt. A range of transition metals can be found in biologically important compounds, such as iron in hemoglobin. Examples: iron pentacarbonyl, titanium tetrachloride, cisplatin

Organolithium reagents are most often found in polymeric form, such as n-butyllithium shown here. Usually, organometallic compounds are considered to contain the M-C-H group.[5] The metal (M) in these species can either be a main group element or a transition metal. Operationally, the definition of an organometallic compound is more relaxed to include also highly lipophilic complexes such as metal carbonyls and even metal alkoxides.

### Conclusion

Main group compounds have been known since the beginnings of chemistry, e.g., elemental sulfur and the distillable white phosphorus. Experiments on oxygen,  $\text{O}_2$ , by Lavoisier and Priestley not only identified an important diatomic gas, but opened the way for describing compounds and reactions according to stoichiometric ratios. The discovery of a practical synthesis of ammonia using iron catalysts by Carl Bosch and Fritz Haber in the early 1900s deeply impacted mankind, demonstrating the significance of inorganic chemical synthesis. Typical main group compounds are  $\text{SiO}_2$ ,  $\text{SnCl}_4$ , and  $\text{N}_2\text{O}$ . Many main group compounds can also be classed as “organometallic”, as they contain organic groups, e.g.,  $\text{B}(\text{CH}_3)_3$ . Main group compounds also occur in nature, e.g., phosphate in DNA, and therefore may be classed as bioinorganic. Conversely, organic compounds lacking (many) hydrogen ligands can be classed as “inorganic”, such as the fullerenes, buckytubes and binary carbon oxides.

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