Inorganic chemistry

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A chemistry laboratory

Introduction

Inorganic chemistry is a subdiscipline of chemistry involving the scientific study of the properties andchemical reactions of all chemical elements and chemical compounds other than the vast number of organic compounds (compounds containing at least one carbon-hydrogen covalent bond).[1][2]

There are a number of subdivisions of inorganic chemistry such as the five subdivisions of the American Chemical Society's Division of Inorganic Chemistry (ASC DIC), namely organometallic chemistry, bioinorganic chemistry, solid-state and materials chemistry, coordination chemistry and nanoscience.[3]

Inorganic chemistry is closely related to other disciplines such as materials science, earth science, mineralogy, geology and crystallography.

Distinctions between inorganic and organic chemistry

The distinction or boundary between inorganic chemistry and organic chemistry is not very well defined. In general, the above definition of inorganic chemistry seemingly excludes carbon compounds but it does not exclude elemental carbon itself. Hence, carbon oxides, carbon sulfides, cyanides and cyanates, metallic carbides and carbonates are included as inorganic compounds.[4]

As another example of the ill-defined distinction between inorganic and organic chemistry, oxalic acid ($H_2C_20_4$) is commonly considered to be an organic compound even though it does not contain a carbon-hydrogen bond.

Classification of inorganic compounds

Inorganic chemistry encompasses a very complicated variety of substances which the distinguished American chemist, F. Albert Cotton (1930 − 2007), grouped into these four classes:[5]

The chemical elements: These have a variety of structure and properties and include:

- Atomic gases such as argon (Ar) and krypton (Kr), as well as molecular gases such as hydrogen (H_2) andoxygen (O_2).
- Molecular solids such as the phosphorus allotrope (P_4), the sulfur allotrope (S_8), and the carbon allotrope (C_{60}).[6]
- Network solids such as diamonds and graphite.[7]
- Metals, either solid such as copper (Cu) and tungsten (W) or liquid such as mercury (Hg) and gallium(Ga).

Ionic compounds: These are always solids at 0 °C temperature and 101.325 kPa absolute pressure and include:

- Simple ionic compounds such as sodium chloride (NaCl), which are soluble in water or other polar solvents.
- Ionic oxides that are insoluble in water, such as zirconium oxide (ZrO_2) and mixed oxides such as the mineral "spinel" ($MgAl_2O_4$), the mineral "diopside" ($CaMg(SiO_3)_2$) and various silicates.

- Other binary halides, carbides, arsenides, nitrides and similar materials. A few examples are silver chloride (AgCl), silicon carbide (SiC), gallium arsenide (GaAs), and boron nitride (BN), some of which could also be considered to be network solids.
- Compounds containing polyatomic ions (also called "complex ions") such as the silicon hexafluoride anion $[SiF_6]^{2-}$, the cobalt hexammine cation $[Co(NH_3)_6]^{3+}$ and the ferricyanide anion $[Fe(CN)_6]^{3-}$.

Molecular compounds: These may be solids, liquids or gases and include:

- Simple binary compounds such as phosphorus trifluoride (PF_3), sulfur dioxide (SO_2) and osmium tetroxide (OsO_4).
- Organometallic compounds that characteristically have metal−to−carbon bonds such as nickel carbonyl ($Ni(CO)_4$) and tetra-benzyl-zirconium ($Zr(CH_2C_6H_5)_4$).
- Complex metal-containing compounds.

Inorganic polymers and superconductors: These include various inorganic polymers and superconductors. One example is the polymer named yttrium barium copper oxide ($YBa_2Cu_3O_7$) which is commonly abbreviated as YBCO. It is a crystalline chemical compound and was the first material to achieve superconductivity above the boiling point of liquid nitrogen (77 K).[8]

Typical inorganic chemical reactions

There is no universally accepted list of the typical, important inorganic reactions. Although there are numerous available sources (books, journal and Internet websites) that include such lists, they all differ to some extent from each other. The inorganic reaction types listed and explained below were drawn from many of the available sources:[5][9][10][11][12]

Synthesis reaction: (also referred to as ***combination*** or ***composition*** reaction)

This is a reaction in which two or more reactants combine to form a single product, where each reactant is a chemical element or compound and the reaction product consist of the two reactants. Examples include:

- sodium + chlorine ⇒ sodium chloride

$2Na + Cl_2 \Rightarrow 2NaCl$

- carbon dioxide + water ⇒ carbonic acid

$CO_2 + H_2O \Rightarrow H_2CO_3$

- hydrogen + sulfur ⇒ hydrogen sulfide

$H_2 + S \Rightarrow H_2S$

Decomposition reaction: (may be ***thermal***, ***electrolytic*** or ***catalytic*** decomposition reaction)

This is a reaction in which a chemical compound is separated into elements or simpler compounds. It is often defined as being the opposite of a synthesis reaction. Examples include:

- hydrogen peroxide ⇒ water + oxygen (Hydrogen peroxide spontaneously decomposes into water and oxygen)

$2H_2O_2 \Rightarrow 2H_20 + O_2$

- calcium carbonate + heat ⇒ calcium oxide + carbon dioxide (Heated calcium carbonate decomposes into calcium oxide and gaseous carbon dioxide)

$CaCO_3 + heat \Rightarrow CaO + CO_2$

Single displacement reaction: (also referred to as ***substitution*** or ***single replacement*** reaction)

This is a reaction characterized by one element being displaced from a compound by another element. Examples include:

- copper + hydrochloric acid ⇒ cupric chloride + hydrogen

$Cu + 2HCl \Rightarrow CuCl_2 + H_2$

- zinc + cupric sulfate ⇒ copper + zinc sulfate

$Zn + CuSO_4 \Rightarrow Cu + ZnSO_4$

Metathesis reaction: (also referred to as ***exchange*** or ***double displacement*** or ***double replacement*** reaction)

This is a reaction in which two compounds exchange bonds or ions to form new, different compounds. Examples include:

- sodium sulfate + barium chloride ⇒ barium sulfate + sodium chloride

$Na_2SO_4 + BaCl_2 \Rightarrow BaSO_4 + 2NaCl$

- silver nitrate + hydrochloric acid ⇒ nitric acid + silver chloride

$AgNO_3 + HCl \Rightarrow HNO_3 + AgCl$

Precipitation reaction: (a specific type of metathesis referred to as ***aqueous metathesis***)
This is a reaction that occurs when two inorganic salt solutions, as in the example below, react to form a solution containing a soluble product and another product that is insoluble and precipitates out of the solution:

- calcium chloride + silver nitrate ⇒ calcium nitrate + silver chloride (Insoluble silver chloride precipitates out of the aqueous solution.)

$CaCl_2$ (aq) + 2$AgNO_3$ (aq) ⇒ $Ca(NO_3)_2$ (aq) + 2AgCl (s)

Neutralization reaction: (another specific type of metathesis that is sometimes referred to as an ***acid-base*** reaction)
This is a reaction in which an acid and a base react to form a salt. Water is also produced in neutralizations with Arrhenius acids,[13] that dissociate in aqueous solution to form hydrogen ions (H^+), and Arrhenius bases, that form hydroxide ions (OH^-). However, water is not produced in all neutralizations as can be seen below in the neutralization of ammonia. Examples include:

- nitric acid + sodium hydroxide ⇒ sodium nitrate + water

HNO_3 + NaOH ⇒ $NaNO_3$ + H_2O

- hydrochloric acid + ammonia ⇒ ammonium chloride

HCl + NH_3 ⇒ NH_4Cl

Redox reaction: (also referred to as ***oxidation-reduction*** reaction)
This is a reaction in which the oxidation numbers of atoms are changed. Examples include:

- hydrogen + fluorine ⇒ hydrogen fluoride

H_2 + F_2 ⇒ 2HF

Hydrogen is oxidized by its oxidation number increasing from zero to +1. Fluorine is reduced by its oxidation number decreasing from zero to -1.

- iron + cupric sulfate ⇒ ferrous sulfate + copper

Fe + $CuSO_4$ ⇒ $FeSO_4$ + Cu

Iron is oxidized by its oxidation number increasing from zero to +2. Copper is reduced by its oxidation number decreasing from +2 to zero.

Analysis and characterization of inorganic compounds

The number of known chemical elements that occur naturally on Earth is 94 and the number of diverse inorganic chemical compounds derived by combinations of those elements is virtually innumerable. The characterization of those compounds includes the measurement of chemical and physical properties such as boiling points, melting points, density, solubility, refractive index and the electrical conductivity of solutions.

The techniques of qualitative and quantitative analytical chemistry can provide the composition of a chemical compound in terms of its constituent chemical elements and can thus determine the chemical formula of a compound.

Modern laboratory equipment and techniques can provide many more details for characterizing chemical compounds. Some of the more commonly used modern techniques are:

- **Chromatography:** A process for separating mixtures of chemicals into their component constituents.
- **X-ray diffraction** or **X-ray crystallography:** A technique that determines the three-dimensional arrangement of atoms within a molecule.
- **Spectrometry** or qualitative **Spectroscopy:** A technique for the identification of substances through the electromagnetic spectrum emitted from or absorbed by them.
- **Voltammetry:** An electrochemical method for studying a chemical substance by measuring the electrical potential and/or electric current in an electrochemical cell containing the substance.

References

1. Inorganic Chemistry: A Study Guide, From the website of the University of Waterloo, Canada

2. Christopher G. Morris (Editor) (1992), *Academic Press Dictionary of Science and Technology*, 1st Edition, Academic Press, ISBN 0-12-200400-0.
3. Welcome to the ACS DIC Webpage!, From the website of the American Chemical Society Division of Inorganic Chemistry.
4. **Note:** For example, carbon monoxide (CO), carbon dioxide (CO_2), carbon disulfide (CS_2), sodium cyanide (NaCN), potassium cyanate (KOCN), silicon carbide (SiC) and calcium carbonate ($CaCO_3$)
5. F. Albert Cotton, Geoffrey Wilkinson and Paul L. Gaus (1995), *Basic Inorganic Chemistry*, 3rd Edition, John Wiley, ISBN 0-471-50532-3.First published in 1976 with Professor F. Albert Cotton of Texas A&M University as the main author.
6. **Note:** Allotropes are molecules having different molecular structures. This differs from isotopes which are elements having different atomic structures (i.e., the same number of protons but different numbers of neutrons in the atomic nucleus). The carbon allotrope (C_{60}) is also known as Buckminsterfullerine.
7. **Note:** Network solids are chemical compounds with the atoms being bonded by covalent bonds in a continuous network. Thus, there are no individual molecules in a network solid and the entire solid may be considered to be a macromolecule. Diamond is an example of a network solid with a continuous network of carbon atoms. Another example is graphite, which consists of continuous two dimensional layers of carbon atoms covalently bonded within each layer and with other bond types holding the layers together.
8. Yttrium Barium Copper Oxide – YBCO, From the wiki of the Chemistry Department at Imperial College, London, England.
9. P.A. Cox (2004), *Inorganic Chemistry*, 2nd Edition, Taylor & Francis, ISBN 1-85996-289-0.
10. Types of Equations, From the website of the Virginia Polytechnic Institute and State University.
11. Types of Inorganic Chemical Reactions: Four General Categories, Dr. Anne Marie Helmenstine on the website of About.com: Chemistry.
12. Types of Chemical Reactions: List of Common Reactions and Examples, Dr. Anne Marie Helmenstine on the website of About.com: Chemistry.
13. **Note:** An Arrhenius acid is defined as dissociating in aqueous solution to form hydrogen ions and Arrhenius bases, which form hydroxide ions. There are a number of other theories and definitions of acids, namely Brønsted–Lowry acid–base theory, Lewis acids and bases,Usanovitch definition, and various others.

Source:
http://www.eoearth.org/view/article/51cbf2757896bb431f6a96fc/?topic=51cbfc98f702fc2ba812eaa6