Noble Gases
(No ionization)
Cations that coordinate with H_2O (or CO_3^{2-} or SO_4^{2-}) in solution
"Hard" or "Type A" Cations
(All electrons removed from outer shell)
(Thus a noble-gas-like configuration of the outer shell)
Coordinate F>O>N=Cl>Br>I>S
Commonly coordinate with O of carboxyl groups of organic ligands
See also Insets 1 to 5 and 7.
Cations that coordinate with OH^- (or H_2O) in solution
Cations that coordinate with OH^- or O^{2-} in solution
Cations that coordinate with O^{2-} in solution (e.g., as NO_3^-, PO_4^{3-}, SO_4^{2-}, etc.)
Outline solid for naturally occurring elements or ions; dashed for ones that rarely or never occur in nature.
Symbol (see scale at far right)
Element Name
Atomic Mass
Naturally occurring isotopes
Atomic Number (number of protons)
Ionic Radius (r) (Å) (or elemental radius for elemental forms)
Most abundant (bold)
Radioactive (italicized)
Radioactive decay pathways
z/r = ionic charge ÷ ionic radius = ionic potential or charge density
Ions that tend to enter into and/or stay in O^{2-}-bearing solids
Ions least depleted from mantle in formation of crust
Ions enriched in CAIs (Ca-Al-rich inclusions in meteorites) relative to the composition of the solar system
Ions that enter early-forming phases in igneous rocks
Ions commonly concentrated in residual soils and residual sediments. Small symbol indicates less certainty.
Ions concentrated in deep-sea ferromanganese nodules relative to seawater
Ions that tend to only enter O^{2-}-bearing solids late, or not at all, and instead to enter or remain in aqueous solution.
Ions that enter later phases in igneous rocks because of their large size (mostly "large-ion lithophiles")
8 most abundant solutes dissolved in seawater
9th to 16th most abundant
17th to 22nd most abundant
Most abundant solute in average river water (HCO_3^-)
2nd to 8th most abundant solutes in average river water
Solutes that can be limiting nutrients in the growth of bacteria
Solutes that can be limiting nutrients in the oceans
Macronutrient solutes on land
Micronutrient solutes on land
Ions essential to the nutrition of at least some vertebrates ("essential minerals")
Cations that form simple fluoride minerals
Cations that form simple oxide minerals
Cations that form simple sulfide minerals
Cations that form simple bromide or iodide minerals
Cations that form oxysalt minerals (e.g., S^{6+} in sulfates, As^{5+} in arsenates)
Anions that form minerals with K^+ and Na^+
Anions that form minerals with Mg^{2+}
Anions that form minerals with Al^{3+}, Ti^{4+}, and Zr^{4+}
Anions that form minerals with Si^{4+}
Anions that form minerals with Cu^+
Anions that form minerals with Ag^+
Anions that form minerals with Au^+
Elements that occur as native minerals, recognized in antiquity (recognized from Middle Ages to 1862; recognized after 1963.)
Elements that make natural mineral alloys with Fe
Elements that make natural mineral alloys with Cu
Elements that make natural mineral alloys with Os
Elements that make natural mineral alloys with Pt
Elements that make natural mineral alloys with Au
4 most abundant constituents in atmosphere
5th to 8th most abundant
Fe 10 most abundant elements in Earth's crust
Zr 11th to 20th most abundant elements in Earth's crust
Li 21st to 40th most abundant elements in Earth's crust
Lu 41st to 92nd most abundant elements in Earth's crust
Elements that are thought to make up most of the Earth's core (Fe>Ni>Co), along with possibly S or O
Intermediate Cations
(Some electrons remain in outer shell)
Coordination with S or O likely
Cations that coordinate with O^{2-} (± OH^-) in solution
Elemental Forms
(uncharged)
other than noble gases
Principal elements in iron meteorites (Fe>>Ni>>Co) and, with S or O, presumably dominant elements in Earth's core
Metals
Non-metals
Gases
Anions
with incomplete outer electron shells
Anions
with full outer electron shells
Anions that commonly coordinate with H^+ (e.g., as CH_4, NH_3, H_2S, H_2O, etc.)
Anions with which hard cations preferentially coordinate
Intermediate
Anions with which soft cations preferentially coordinate
"Soft" ("Type B") Cations
(Many electrons remain in outer shell)
Coordinate I>Br>S>Cl=N>O>F
Commonly coordinate with C of organic ligands, as in methylmercury
Elements 95 and beyond do not occur naturally:
*For the sake of simplicity, the ^{235}U-^{207}Pb and ^{232}Th-^{208}Pb series are omitted.
Rare earth elements (REEs)
(effectively "Hard" or "Type A" cations in their 3+ state)
Lanthanides:
Inset 1: Bulk modulus (K_s in GPa) of oxide minerals of hard cations
Inset 2: Hardness of oxide minerals of hard cations
Inset 3: Melting T(K) of oxides of hard cations
Inset 4: Solubility of oxide minerals of hard cations
Inset 5: Typical simple oxysalt minerals (__MO_n minerals without OH or H_2O)
Inset 6: Melting and decomposition (d) temperatures (K) of oxides of intermediate and soft cations
Inset 7: Conceptual model of the behavior of oxides of hard (and intermediate) cations
Inset 8: Solubility of halides of hard and soft cations
Inset 9: The many valence states of nitrogen
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An Earth Scientist's Periodic Table of the Elements and Their Ions

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