# Categorizing anions

An *SFMG* page parallel to this one, *Categorizing cations,* presents two tables to lead earth scientists through a scheme to categorize the more than 100 entities that put positive charge in minerals (i.e., cations). This page similarly tries to categorize anions, but it is different for at least two reasons. First, there are only about fifteen entities that provide negative charge to minerals (anions), so we can just list them all here. Secondly, ionic potential (charge ÷ radius) does not vary nearly so much among anions as among cations, because charge and radius increase together in anions (rather than varying inversely, as in cations). Thus the dominant thought here is just to divide anions between hard and soft, with a secondary emphasis on a gradient from "somewhat soft" to "softer".

Leftward are increasingly improbable anions in $O^{2-}$-rich environments because they instead go to the $C^{4+}$ of carbonate, $Si^{4+}$ of silicates, etc.

$O^{2-}$ is the anion of the most abundant element in Earth's crust. It is thus the dominant anion of crustal minerals (silicates, oxides, carbonates, sulfates, etc.) and in the $H_2O$ of the oceans.

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|---|---|---|---|---|
| $C^{4-}$ χ = 2.5, r = 2.80Å | $N^{3-}$ χ = 3.0, r = 1.71Å | $O^{2-}$ χ = 3.5, r = 1.40Å | $F^{-}$ χ = 4.0, r = 1.36Å | **Hard** |
| $Si^{4-}$ χ = 1.8, r = 2.71Å | $P^{3-}$ χ = 2.1, r = 2.12Å | $S^{2-}$ χ = 2.5, r = 1.84Å | $Cl^{-}$ χ = 3.0, r = 1.81Å | **Somewhat soft** |
| | $As^{3-}$ χ = 2.0, r = 2.22Å | $Se^{2-}$ χ = 2.4, r = 1.98Å | $Br^{-}$ χ = 2.8, r = 1.95Å | ↕ |
| | $Sb^{3-}$ χ = 1.9, r = 2.45Å | $Te^{2-}$ χ = 2.1, r = 2.21Å | $I^{-}$ χ = 2.5, r = 2.16Å | |
| | $Bi^{2-}$ χ = 1.9 | | | **Softer** |

Hard anions, with their small and relatively undeformable clouds of electrons, form bonds of a more ionic character and thus typically coordinate with hard cations (e.g., $Na^{+}$, $K^{+}$, $Mg^{2+}$, $Ca^{2+}$, $Al^{3+}$, $Si^{4+}$).

This gap is intended to emphasize the difference in behavior between the hard anions of the top row, especially $O^{2-}$ and $F^{-}$, and the softer anions below.

$Cl^{-}$ bonds effectively to neither hard nor soft cations (and thus it's a lousy ligand). Its failure to bond in solids is why it is the most abundant solute in seawater and in most deep-basin brines.

Soft anions, with their larger and more deformable clouds of electrons, form bonds of a more covalent character and thus typically coordinate with intermediate to soft cations. (e.g., $Fe^{2+}$, $Cu^{2+}$, $Zn^{2+}$, $Ag^{+}$, $Hg^{+}$).

Radius (r) of the ionic form. Note, within each column, the abrupt decrease from soft to hard (for example, from Cl to F or from S to O)

Electronegativity (χ) of the elemental form (a measure of tendency to attract electrons). Note, within each column, the abrupt increase from soft to hard (for example, from Cl to F or from S to O)

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