

General Rules for the Chemical Sensitivity of Minerals

When chemical stability for a specific mineral or reagent is unavailable, some general guidelines can be useful for making predictions. The following rules are drawn directly from the literature as well as generalizations made during the preparation of this data base. This data is useful primarily for cleaning, development and conservation of mineral specimens but may also have some utility for mineral identification. Detailed cleaning procedures are not given; for these see a work devoted to the subject such as [Mineral Specimen Cleaning and Development for the Amateur](http://www.mincleandev.com/min_clean_dev.pdf) (http://www.mincleandev.com/min_clean_dev.pdf).

A lack of data for a given mineral species versus a given reagent is because no data was found in the literature. This lack of data should not be construed as resistance or inertness to a particular reagent. Whenever possible test with lower quality specimens (preferably from the same locality) before committing any precious specimens. Published statements such as “soluble in HCl” or “acid resistant” should normally be regarded as screening information, not a guarantee for a particular species or specimen. This list is (obviously) incomplete, but instead a mere summary of literature generalizations.

Most chemical properties of minerals are derived from the anions present (carbonate, sulfate, silicate, etc.). The following generalities reflect that control. When multiple anions are present in a mineral, treat the specimen based on the most sensitive anion(s) present. Numerous other factors can also influence chemical sensitivity and must be considered as well, including crystal structure, crystal size and surface area, cation and anion oxidation states, water of hydration (or lack thereof), defects, inclusions, etc. Reagent-specific issues that must be considered include reagent concentration and temperature, pH, time of exposure, etc.

More specific and/or more precise information might be gleaned by assembling a list of chemically similar minerals based on their [Strunz-Mindat classification](https://www.mindat.org/strunz.php) (<https://www.mindat.org/strunz.php>) then compiling the chemical sensitivities for all minerals on this list. However, take care when make broad generalizations within a class as exceptions are not uncommon.

Aluminosilicates: Feldspars are generally resistant to ordinary dilute acids but can be attacked by strong alkaline or NH_4HF_2 solutions. When considering treatment with hot alkali, strong acids or NH_4HF_2 specimen-specific testing is advised. See also silicates and zeolites.

Antimonides (Sb^{3-} and polymeric Sb anions): May be soluble in HNO_3 .

Arsenates (AsO_4^{3-}) and Arsenites (AsO_3^{3-}): The chemical stability of this mineral group is rather variable. Some are water soluble. Many are substantially acid sensitive, including solubility in HCl . Ca arsenates of pharmacolite series minerals are soluble in weak acids. Pb arsenates are often soluble in HNO_3 . Treat arsenates as acid sensitive.

Arsenides (As^{3-} and polymeric As anions): May be soluble HNO_3 .

Arsenites: See Arsenates.

Bicarbonates: See Carbonates.

Borates (BO_3^{3-} , BO_4^{5-} and hydrated borates): Hydrated alkali-metal borates can be extremely water sensitive. Na borates are readily water soluble whereas Ca or Mg borates are generally much less soluble. Water sensitivity is a major concern for Na or K borates. Borates containing water of hydration are often soluble in water or acids whereas borates lacking water of hydration are often insoluble in water or acids. Strong mineral acids generally decompose borates with many borates soluble in HCl .

Carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-): Carbonates are the principal acid-sensitive mineral group. Most common Ca, Mg, Fe, Mn, Zn, Pb and Cu carbonates should be presumed acid sensitive unless demonstrated otherwise. Most carbonates are insoluble in water. Pb carbonates are often soluble in HNO_3 . Treat carbonates as acid sensitive unless demonstrated otherwise.

Chromates (CrO_4^{2-}) and Dichromates ($\text{Cr}_2\text{O}_7^{2-}$): Chromates should be considered chemically sensitive and potentially redox-sensitive. The behavior of chromate is fundamentally different from that of the much more common silicate and carbonate groups.

Copper minerals: May be sensitive to dithionite and other reducing agents.

Dichromates: See Chromates.

Disulfides: See Sulfides.

Halides (F^- , Cl^- , Br^- and I^-): Alkali-metal chlorides are generally water sensitive, whereas insoluble heavy-metal chlorides can behave very differently. Assume serious water sensitivity for a specimen containing Na, K or Mg hydrated chlorides. Fluoride minerals are unusual because their behavior depends strongly on the cation. Do not assume that all fluorides behave like fluorite. Most fluorides are insoluble (or at best poorly soluble) in water and may be attacked by strong acids. Fluorides and chlorides of alkali and alkaline earth cations are often soluble in H_2SO_4 . Chlorides are generally water soluble except those of Pb, Hg or Ag. Bromides and iodides are mostly poorly soluble to insoluble in both water and acids. Cu oxyhalides and Pb and Hg halides may be soluble in weak acids.

Hydroxides (HO^-): Hydroxide minerals are often more acid sensitive than their corresponding oxides. Amphoteric hydroxides can also be attacked by strong alkalis. Acid resistance does not imply alkali resistance. Transition-metal hydroxides are often susceptible to acids and reducing agents. Mn(IV) hydroxides may be soluble in weak acids. Hydroxides of Al and Mg are soluble in HCl.

Iodates (IO_3^-): Solubility varies greatly with the cation.

Molybdates (MoO_4^{2-}): Molybdates are generally insoluble in water and slightly soluble in acids. Many molybdates, especially Ca and Pb molybdates, should not automatically be regarded as acid resistant. Molybdates of Ca, Cu and Fe^{2+} are soluble in HCl.

Nitrates (NO_3^-): Nitrates are often water soluble. Assume water sensitivity until demonstrated otherwise. Especially important for evaporite minerals.

Organic minerals (including acetates, formates and oxalates): Water sensitivity varies widely. Assume sensitivity to organic solvents (methanol, ethanol, isopropanol, acetone, toluene etc.). May be sensitive to oxidants (H_2O_2 , hypochlorite or oxidizing acids).

Oxides (O^{2-}): Oxides are extraordinarily variable. Mostly insoluble in water, with some species - especially Mv(IV) oxides - soluble in weak acids. Many oxides are acid resistant, but transition-metal oxides are often susceptible to acids and reducing agents. Oxides of Mn as well as some oxides of Fe and Zn are soluble in HCl. Complex oxides of Fe, Mg, Ta, Th, Zn, Zr or U are often soluble in H_2SO_4 .

Phosphates (PO_4^{3-} and polyphosphates): These are generally insoluble in water except when the cation is NH_4^+ , K or Na. Many phosphate minerals are acid sensitive or acid soluble (especially to HCl, HNO_3 or H_2SO_4) but not uniformly so. These minerals may tolerate oxalic acid, weak organic acids or chelators, but testing is advised. Pb phosphates are often soluble in HNO_3 . Treat phosphates as acid sensitive.

Polysulfides: See Sulfides.

Polythionates: See Thiosulfates.

Selenates: See Selenites.

Selenides (Se^{2-}) and Tellurides (Te^{2-}): Metal selenides and tellurides require extreme caution with acids and oxidants. Acidification can convert reduced chalcogen species into volatile and toxic selenium- or tellurium-containing compounds such as H_2Se . Acid treatment of selenides or tellurides should not be treated as an ordinary mineral-cleaning operation. Selenides and tellurides may be soluble in HNO_3 . Tellurides of Bi or Au are often soluble in H_2SO_4 .

Selenites (SeO_3^{2-}) and Selenates (SeO_4^{2-}): Selenites and selenates can differ dramatically from the corresponding sulfites or sulfates because selenium has different redox chemistry. Selenite and selenate minerals should therefore be regarded as special-case minerals, with particular attention to acid stability, oxidation state, water solubility and redox conditions. Published solubility literature treats metal selenites as a separate chemical class rather than assuming sulfate-like behavior.

Silicates (SiO_4^{4-} and polymeric silicates): Silicates constitute the largest mineral group and show enormous variation. Silicates are generally insoluble in water or acids but many exceptions (such as zeolites; see below) exist. Common silicates are mostly resistant to ordinary dilute acids, but this does not mean they are chemically inert. Quartz is the classic highly resistant mineral. Many feldspars, pyroxenes, amphiboles, garnets, tourmalines, beryl, zircon and rutile are resistant to dilute HCl. Silica-poor species, especially orthosilicates and aluminosilicates (see above), may be soluble in HCl. Fluoride-containing acidic solutions (NH_4HF_2) can attack silica and silicate minerals very strongly and can damage silicate minerals that appear completely resistant to HCl.

Sulfate (SO_4^{2-}): Sulfates range from highly water soluble to moderate solubility to extremely acid resistant. Sulfates of Pb, Ca or Ba have moderate to very poor water solubility. Dissolution is more rapid when water of hydration is present.

Sulfides (S^{2-}), Disulfides and Polysulfides: This is one of the most complicated groups because redox chemistry becomes at least as important as acid-base chemistry. Do not equate “sulfide” with “acid soluble.” They are generally insoluble in water and slightly soluble to insoluble in acids. These minerals become more sensitive in the presence of an oxidant. “Simple” sulfides of Sb, Bi, Cd, Fe, Mn or Zn are soluble in HCl. Sulfides of Sb, Bi, Cu, Pb, Mo, Ni, Ag or W are often soluble in HNO_3 . Sulfides may be sensitive to oxidants (H_2O_2 , hypochlorite or oxidizing acids). Treat sulfides primarily as redox-sensitive, not merely acid-sensitive.

Sulfites (SO_3^{2-}): Sulfites are generally more chemically reactive than corresponding sulfates and can often be oxidized to sulfate.

Sulfosalts: Often sensitive to HNO_3 .

Tellurates (TeO_4^{2-}) and Tellurites (TeO_3^{2-}): Tellurite and tellurate are not chemically interchangeable, as tellurite contains Te(IV), whereas tellurate contains Te(VI), so oxidation-reduction conditions can change the mineral's stability. Because tellurium compounds can produce hazardous species under inappropriate chemical conditions (especially treatment with strong acids), these minerals should be treated as specialized cases rather than with generic rules.

Tellurides: See Selenides

Tellurites: See Tellurates.

Thiosulfates ($\text{S}_2\text{O}_3^{2-}$) and Polythionates: Thiosulfate and polythionate minerals should be considered chemically labile, particularly toward acids and oxidants. Acidification can produce sulfur-containing decomposition products, frequently toxic H_2S gas. Oxidation can convert reduced sulfur species toward sulfate.

Tungstates (WO_4^{2-}): The chemical properties of these minerals are highly dependent on the cation. For example, Ca tungstate is substantially different chemically from Fe or Mn tungstates, so do not extrapolate the resistance of scheelite to wolframite, or vice versa. Tungstates are generally insoluble in water or acids. Tungstates of Ca, Cu or Fe^{2+} are generally soluble in HCl. Strong acids and strongly alkaline solutions can alter tungstate minerals through protonation, dissolution and formation of tungstic-acid and/or soluble tungstate species.

Vanadates (VO_4^{3-}): Many vanadates are considerably more chemically sensitive than common silicates. These minerals are generally insoluble in water but slowly attacked by to soluble in acids. Many are soluble in HCl. Pb vanadates are often soluble in HNO_3 . Acids can protonate vanadate species and promote dissolution, while alkaline conditions can stabilize soluble vanadate species. Avoid assuming that a hard, well-formed vanadate crystal is chemically robust.

Zeolites: Zeolites can be chemically sensitive because of open framework structures, exchangeable cations, structural water and variable Si/Al ratios. The acid stability of zeolites is controlled mainly by silicon content. Low-silica zeolites react with acids (especially HCl) more quickly than high-silica zeolites. Some high-silica zeolites are surprisingly acid resistant. Some zeolites are water sensitive.

Selected References

For chemical stabilities of specific minerals and references see individual species entries.

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