Aluminum and water: reaction mechanisms, environmental impact and health effects

The amount of aluminum in seawater varies between approximately 0.013 and 5 ppb. The Atlantic Ocean is known to contain more aluminum than the Pacific Ocean. River water generally contains about 400 ppb of aluminum.
Aluminum mainly occurs as Al^{3+} (aq) under acidic conditions, and as $Al(OH)_4^-$ (aq) under neutral to alkalic conditions. Other forms include $AlOH_2^+$ (aq) en $Al(OH)_3$ (aq).

In what way and in what form does aluminum react with water?

Aluminum metal rapidly develops a thin layer of aluminum oxide of a few millimeters that prevents the metal from reacting with water. When this layer is corroded a reaction develops, releasing highly flammable hydrogen gas.
Aluminum chloride hydrolyses in water, and forms a mist when it comes in contact with air, because hydrochloric acid drops form when it reacts with water vapor.
Aluminum ions in other compounds also hydrolyze, and this continues until the cationic charge has run out, ending the reaction by hydroxide formation. The beginning of the hydrolysis reaction is as follows:

$Al^{3+}(aq) + 6H_2O(l) <-> [Al(H_2O)_6]^{3+}$ (aq)

Solubility of aluminum and aluminum compounds

The most abundant aluminum compounds are aluminum oxide and aluminum hydroxide, and these are water insoluble.
Aluminum oxide may be present in water both in alkalic form ($2Al_2O_3$ (s) + $6H^+$ (aq) -> Al^{3+} (aq) + $3H_2O$ (l)) and in acidic form ($2Al_2O_3$ (s) + $2OH^-$ (aq) -> AlO_2^- (aq) + H_2O (l)).
An example of a water soluble aluminum compound is aluminum sulphate with a water solubility of 370

g/L.

Why is aluminum present in water?

Aluminum forms during mineral weathering of feldspars, such as and orthoclase, anorthite, albite, micas and bauxite, and subsequently ends up in clay minerals. A number of gemstones contain aluminum, examples are ruby and sapphire.
Currently, only iron and steel are produced in larger amounts than aluminum. Additionally, aluminum is largely recycled because this is very distinctly possible. It is applied in for example frames, door knobs, car bodies, plane parts (the weight/ strength relation is very favourable), engines, cables and cans. Aluminum is a good reflector and is therefore applied in solar mirrors and heat reflecting blankets. Aluminum is processed to cans, wiring and alloys.
Aluminum salts are often added to water to start precipitation reactions for phosphate removal.
Consequently, sewage sludge in water purification with a pH value between 6.8 and 7.3 is present as hydroxides.
Alums are applied as fertilizer in tea plantations. Other aluminum compounds are applied in paper production. Alloys such as duraluminum are applied because these are stronger than aluminum itself.
Aluminum foam is applied in tunnels as soundproofing material.
Other examples of aluminum application include aluminum chloride use in cracking processes, aluminum oxide as an abrasive or for production of inflammable objects, aluminum sulphate use as a basic material in paper glue, tanners, mordants and synthetic rubber, and aluminum hydrogen as a reduction and hydration agent.
Aluminum occurs as an aerosol in oceanic surface layers and in waters. This is because aluminum dust end up in water. Particles end up in water through surface run-off or atmospheric transport.
Generally, aluminum concentrations increase with increasing water depth.

What are the environmental effects of aluminum in water?

Aluminum may negatively affect terrestrial and aquatic life in different ways. Regular aluminum concentrations in groundwater are about 0.4 ppm, because it is present in soils as water insoluble hydroxide. At pH values below 4.5 solubility rapidly increases, causing aluminum concentrations to rise above 5 ppm. This may also occur at very high pH values.
Dissolved Al^{3+}-ions are toxic to plants; these affect roots and decrease phosphate intake. As was mentioned above, when pH values increase aluminum dissolves. This explains the correlation between acid rains and soil aluminum concentrations. At increasing nitrate deposition the aluminum amount increases, whereas it decreases under large heather and agricultural surfaces. In forest soils it increases.
Aluminum is not a dietary requirement for plants, but it may positively influence growth in some species. It is taken up by all plants because of its wide distribution in soils. Grass species may accumulate

aluminum concentrations of above 1% dry mass.
Acid rain dissolves minerals in soils, and transports these to water sources. This may cause aluminum concentrations in rivers and lakes to rise.
Aluminum naturally occurs in waters in very low concentrations. Higher concentrations derived from mining waste may negatively affect aquatic biocoenosis. Aluminum is toxic to fish in acidic, unbuffered waters starting at a concentration of 0.1 mg/L. Simultaneous electrolyte shortages influence gull permeability, and damage surface gull cells. Aluminum is mainly toxic to fish at pH values 5.0-5.5. Aluminum ions accumulate on the gulls and clog these with a slimy layer, which limits breathing. When pH values decrease, aluminum ions influence gull permeability regulation by calcium. This increases sodium losses. Calcium and aluminum are antagonistic, but adding calcium cannot limit electrolyte loss. This mainly concerns young animals. An aluminum concentration of 1.5 mg/L turned out to be fatal to trout.
The element also influences growth of freshwater bony fish.
Phytoplankton contains approximately 40-400 ppm aluminum (dry mass), which leads to a bioconcentration factor of 10^4-10^5 compared to seawater.
Terrestrial organisms also contain some aluminum. Examples: mosquito larvae 7-33 ppm, springtails 36-424 ppm (dry mass). Together, pH values and aluminum concentrations determine larvae mortality.
A number of LD_{50} values for rats are known for aluminum. For oral intake this is 420 mg/kg for aluminum chloride, and 3671 mg/kg for aluminum nonahydrate. The mechanism of toxicity is mainly based on enzyme inhibition.
Only one non-radioactive aluminum isotope occurs naturally. There are eight instable isotopes.

What are the health effects of aluminum in water?

The total aluminum concentration in the human body is approximately 9 ppm (dry mass). In some organs, specifically the spleen, kidneys and lung, concentrations up to 100 ppm (dry mass) may be present. Daily aluminum intake is approximately 5 mg, of which only a small fraction is absorbed. This leads to relatively low acute toxicity. Absorption is about 10 µg per day. These amounts are considered harmless to humans. Silicon may decrease aluminum uptake. However, once the element is taken up in the body it is not easily removed.
Large aluminum intake may negatively influence health. This was connected with nerve damage. Particularly people with kidney damage are susceptible to aluminum toxicity. There is a risk of allergies. Aluminum is probably mutagenic and carcinogenic. A correlation between aluminum uptake and an increased number of Alzheimer cases is suspected. However, this is uncertain because aluminum concentrations always increase with age. Increased aluminum intake may also cause osteomalacia (vitamin D and calcium deficits).
Aluminum intake mainly occurs through food and drinking water. The most recent standards were between 50 and 200 µg/L. Aluminum particles may cause functional lung disorder.
No known diseases are linked to aluminum shortages.
Aluminum chloride may corrode the skin, irritate the mucous membranes in the eyes, and cause

perspiration, shortness of breath and coughing. Alum increases blood clotting.

Which water purification technologies can be applied to remove aluminum from water?

Aluminum may be removed from water by means of ion exchange or coagulation/ flocculation. Aluminum salts are applied in water treatment for precipitation reactions. Adding aluminum sulphate and lime to water causes aluminum hydroxide formation, which leads to settling of pollutants. Hydroxide is water insoluble, therefore only 0.05 ppm dissolved aluminum remains. This is below the legal limit for drinking water of the World Health Organization (WHO), of 0.2 ppm aluminum.

Literature and the other elements and their interaction with water

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