

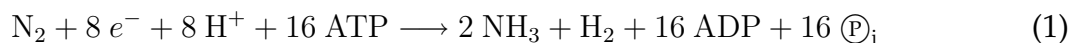
The Nitrogen Cycle for Aquarium Enthusiasts

Nitrogen is an essential part of our environment and our own physiology. It is found in all amino acids and therefore in proteins, in the bases that make up DNA, and many other places. And, if you are an aquarium neophyte, it could just kill all of your fish if you aren't careful.

Nitrogen is found in heavy concentrations in the atmosphere, which is 78% N₂ by volume (Wikipedia contributors, 2004b). From here it makes its way into the soil, into plants, into animals, and back into the atmosphere. This is a simplified overview of the nitrogen cycle; the full story is much more complex. I will focus mainly on what is useful for an aquarium enthusiast to know.

1 Out of the air

Nitrogen is abundant in the air, and some of it settles to the ground as a thin layer or makes it into the soil dissolved in rainwater. Some plants have above-ground roots that can take in this nitrogen, but most organisms cannot utilize atmospheric N₂ (Campbell and Reece, 2002). There are some creatures who can, however, turn N₂ gas into a form more readily usable. They are microscopic organisms, such as bacteria in soil and cyanobacteria in water (see Fig. 1), and are said to “fix” nitrogen. This means that they capture the free-floating N₂ from the air and convert it into ammonia (NH₃) in a process catalyzed by nitrogenase (Deacon, 2004b):



Some plants have symbiotic relationships with these bacteria. An example is legumes, which have *Rhizobium* bacteria inside their root nodules. The nitrogenous compounds created by these bacteria help fertilize the soil. This effect has been exploited for thousands of years in the agricultural strategy of crop rotation, and remains particularly important in organic farming and in less developed countries that cannot afford heavy artificial fertilization. (Priesnitz, 1998).

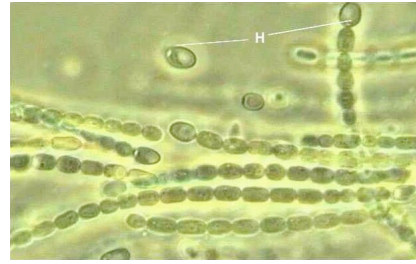


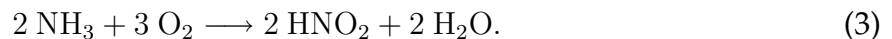
Figure 1: *Nostoc* bacteria. Nitrogen fixation occurs in the heterocyst, which is marked with an “H” (Deacon, 2004a)

2 In the soil or water

In soil, which is usually slightly acidic, ammonia will pick up an extra hydrogen ion to become ammonium (NH_4^+), which can be used directly by plants (Campbell and Reece, 2002). In aquatic environments, ammonia will combine with water to form ammonium hydroxide,



which is extremely toxic and corrosive. However, in both soil and water, there exists a genus of bacteria called *Nitrosomonas* (see Fig. 2) that oxidates ammonia to nitrite (NO_2^-):



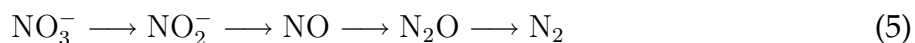
Nitrite is also toxic, but it, in turn, is converted into nitrate (NO_3^-) by the bacteria *Nitrobacter* (see Fig. 3):



Nitrate is not toxic at regular levels; in fact it is a plant nutrient, and will fuel the growth of soil-based plants or aquatic plants and algae (Devos et al., 2004).

3 Closing the loop

We have now traced nitrogen from the air all the way to the insides of plants. From here most of it remains in the terrestrial part of the cycle as, for instance, a plant is consumed by an animal. The animal can then return the nitrogen to the soil or water in the form of feces or by decomposition upon death, where ammonifying fungi and bacteria convert nitrogen from organic materials into ammonia. Nitrogen can return to the atmosphere when processed by denitrifying bacteria in a chain of reactions (Corbin, 1998):



Furthermore, since ammonia is a gas, some of it can escape back into the air without the help of bacteria. Once there, it can form ammonium and fall back down dissolved in rainwater.

4 So what?

What does this mean for your aquarium? When you start a new aquarium, you are essentially working with a blank slate. Tap water is heavily treated with chemicals like chlorine in order to kill off microorganisms that might be harmful to humans; even after dechlorination it will not have much in the way of nitrogen in it. If you opt for a soil base for growing plants you might start with a little nitrogen in there, but that is also not a major source. So where does the nitrogen come from? It comes from your fish!

When you add fish to your aquarium you will, hypothetically, feed them. That food contains nitrogen in the form of plant or animal matter. Fish then excrete that ni-

trogen in the form of ammonia. Why would a fish produce something so toxic? First of all, ammonia is very simple to produce, and it dissolves in water very well. This means that it can pass through membranes very easily. Second, in nature fish generally inhabit much larger aquatic systems, where ammonia's high degree of solubility means it would be difficult to reach toxic concentrations (Campbell and Reece, 2002). On the other hand, in an aquarium, which is far from the balanced ecosystems fish enjoy in nature, ammonia can build up fairly quickly. In the presence of *Nitrosomonas* and *Nitrobacter* that ammonia would be ultimately converted into nitrate, which is relatively harmless to the fish. But in a newly established aquarium, there are no colonies of these beneficial bacteria, and so the ammonia is left to build up as ammonium hydroxide. If left unchecked, the fish will die.

The process by which these bacterial colonies are established is called tank cycling. It begins when you add fish—they produce food for *Nitrosomonas*, which produces food for *Nitrobacter*, which creates nitrate. When the populations are in balance, ammonia and nitrite are consumed at about the same rate as they are produced, and almost all of the nitrogen in the tank is in the form of nitrate. However, it can take several weeks for the populations to establish themselves, and during this time the fish are in significant danger. There are a number of ways to help the process along, including borrowing bacteria-containing gravel, plants, or decorations from an established aquarium, or adding a nitrifying bacteria starter solution to the water (Hauter and Hauter, 2004).

Once the tank has cycled, ammonia and nitrite will no longer be present in high concentrations. The aquarium is quite safe for fish, unless their ammonia production overwhelms the *Nitrosomonas* population. This is particularly a danger when adding



Figure 2: *Nitrosomonas* bacteria. (Watson, 2003)

many new fish at once. When this happens, the aquarium will have to repeat the cycle as *Nitrosomonas* and then *Nitrobacter* shore up their numbers to meet the new demand. For this reason, it is best to add fish only one or two at a time.

5 The danger of nitrogenous compounds

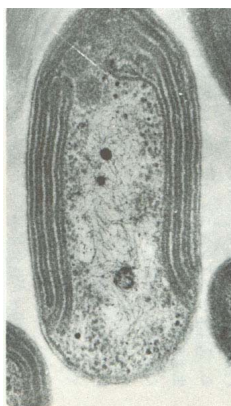


Figure 3: *Nitrobacter* bacteria. (Watoson and Mandel, 1971)

Ammonia causes damage to tissues in two ways. Its conversion to ammonium hydroxide (see Eq. 2) gives off a lot of heat, and can cause burns. This is less of a concern in an aquatic environment, where the ammonia will already have been converted to ammonium hydroxide by the time it comes in contact with the fish. More important is the extreme alkalinity of ammonium hydroxide. At high concentrations it can cause severe chemical burns (Issley, 2001). Even if these burns do not lead immediately to death, increased stress levels in fish usually

result in lower immune response and a heightened danger of infection by waterborne bacteria and fungi. Ammonia concentration is dependent on temperature and, more strongly, on pH. If one cannot kick-start the tank cycle by borrowing material from an established aquarium, the cycle can take multiple weeks to complete. During this dangerous period of high ammonia concentration, it is therefore best to keep the tank's temperature and pH at the low end of the fishes' comfort range. It is recommended that long-term ammonia concentrations in an aquarium not exceed 0.2 mg/L (Frank, 1998).

Nitrite, which is produced from ammonia as in Eq. 3, is also toxic. According to FishDoc (2000), at high levels nitrite "is actively transported across the gills and into the fish's bloodstream, where it oxidizes hemoglobin to methemoglobin. Normal haemoglobin picks up oxygen at the gills and transports it to the body tissues where it is exchanged for

carbon dioxide. Methemoglobin cannot transport oxygen and therefore in acute cases the fish will be effectively asphyxiated." Nitrite toxicity is also affected by salinity. 1/2 ounce per gallon of aquarium salt, along with increased aeration can help reduce the effects of high nitrite levels (FishDoc, 2000).

Nitrate toxicity is largely a function of how much nitrate is converted into other, more toxic nitrogenous compounds. Nitrate poisoning seems to be a problem largely constrained to ruminants, such as cattle, which have enzymes in their rumens that can convert nitrate to nitrite, and nitrite to ammonia. It is difficult, therefore, to talk about the toxicology of nitrate itself, since the physiological effects are really those of nitrite and ammonia (Smith and Guthrie, 1997). In general, excess nitrate in an aquarium will merely lead to unsightly algae growth; you may not be able to see your fish, but they will still be alive. Since most of the nitrogen present in an established aquarium is in the form of nitrate, regular water changes are necessary to prevent such algal blooms. Another option is to introduce algae-eating fish or shrimp. If left unchecked, algal consumption of O₂ can eventually outpace oxygenation of the water, leading to stress and poor health in the fish (Wikipedia contributors, 2004a).

Nitrogen gas is mostly inert, so any ill effects it may cause are actually due to lack of oxygen. However, it is unlikely that nitrogen gas would be dissolved in aquarium water in any great quantity.

There exist many other nitrogen-containing compounds that are potentially harmful, but few, if any, are worth noting in the context of an aquarium.

6 Conclusion

Nitrogen is an important part of the ecology of our whole world, as well as our aquariums. A good understanding of the roles it plays is essential in our duties to protect the earth, and in making a good home for pet fish.

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