CH302H – Principles of Chemistry II: Honors
Fall 2016, Unique 49420

31 March 2016

Hopefully you are all at least a bit aware of the very serious issue of lead contamination of drinking water in the city of Flint, MI, which arose after the city switched its water supply from the city of Detroit (which drew water from Lake Huron), to the Flint River in April 2014. Water from the Flint River began corroding the insides of the lead pipes used in Flint's drinking water distribution system, dissolving the lead. Lead is a potent neurotoxin, particularly to the developing brains of fetus, infants, and young children. Lead is so dangerous that the EPA's accepted limit on lead in drinking water supplies is 0, i.e. no detectable lead at all. Measured lead levels above 15 ppb trigger a series of regulatory actions that a water utility is legally required to take in order to reduce lead concentrations. (ppb = parts per billion, a common concentration term in environmental chemistry; 1 ppb = 1 μg solute per liter of solution.)

At first glance, it might seem that the mistake is in having lead pipes deliver drinking water, but as it turns out, much of the industrialized world safely uses lead pipes to store and deliver drinking water. (The US currently has as much as ~13 million miles of lead pipes in water distribution systems.) The key is the water has to be properly treated to avoid corrosion, and so this entirely an issue of controlling the chemistry of the pipe-water system. There were three basic problems with Flint's new drinking water source and treatment that created this problem, which we will explore here: the lack of additives to prevent corrosion, pH, and bacterial contamination.

1. Suppose that a certain amount of Pb^{2+} has dissolved in water. What salts could be added to the water to precipitate soluble Pb?

2. Detroit's drinking water had been treated with Na_2PO_4. What will this do to any possible lead dissolved in the water? ($K_{sp}(PbCO_3)$~10^{-20}).

3. Measured levels of lead in Flint drinking water were as high as 300 ppb. How much Na_2PO_4 should be added to the water to return lead concentrations to a maximum of 15 ppb?

4. Boston's water supply is also stored and distributed through lead pipes. The Boston water utility treats its water to maintain a pH of 9.6. Why might this help in preventing lead from dissolving in water?

5. Detroit's drinking water was maintained at pH > 8. For unknown reasons, the Flint water utility was not treating the water to maintain a constant pH. Over the course of 2015, the pH of Flint drinking water dropped to 7.3. How might this have further contributed to lead contamination in the water? ($K_{sp}(PbCO_3) \sim 10^{-14}$.)

6. Further problems in Flint were caused by the fact that the water distribution system included iron pipes as well as lead pipes. Iron from these pipes also began dissolving into the water for the same reasons you have discussed above. (The pictures that you have seen in the news of water coming out of Flint taps in revolting shades of yellow are from various forms of iron and iron oxides dissolved in the water.) High concentrations of iron are relatively benign for people, but they are an important nutrient for bacteria and other microorganisms. This resulted in the outbreak of pathogens in Flint's water supply, most notably an outbreak of *E. coli* in 2014 and two outbreaks of *Legionella* in 2014 and 2015.

To treat this biological contamination, Flint's water utility added Cl_2 to the water, just as it is added to swimming pools to disinfect them. The problem is that Fe catalyzes the dissociation of Cl_2 into chloride, Cl^-. Detroit's water utility maintained $[Cl^-]$ at ~11 ppm (parts per million, 1 mg per liter of solution), but $[Cl^-]$ in Flint's water was almost 10 times that. This is a problem because $PbCl_2$ is significantly more soluble than $PbCO_3$ or $PbPO_4$ ($K_{sp}(PbCl_2) \sim 10^{-5}$.)

How much additional Pb^{2+} will dissolve in water based on this difference in $[Cl^-]$?