PHENOMENA:

Lead in the Water: How It Gets There, Why It Matters, Am I at Risk?

TOPICS

Chemistry, Environmental Science, Current Events

GRADE LEVEL

9-12+

INSTRUCTIONAL TIME

One to three 50-minute class periods

Chemistry Connections (optional): One class period

OVERVIEW

In this lesson, the Crowd the Tap citizen science project anchors an investigation into lead drinking water pipes. The educator introduces students to the project by relating how and why the educator conducted a Crowd the Tap test on a local building (private home). After reviewing the results from the local test and the aggregated Crowd the Tap data, students research lead pipes and the risk they pose to human health, using Flint, Michigan, as an example. Then students assess their local risk by using the Crowd the Tap resources to better understand the presence or absence of lead pipes in their community. The optional Chemistry Connections activity enables students to reinforce and apply chemistry understanding to the phenomena.

BACKGROUND

Lead was a commonly used metal for drinking water pipes until negative human health impacts, particularly on the brain, were understood. There are still many lead pipes in use, especially as service lines that connect the main water pipe to the individual home. To help prevent lead poisoning, the Environmental Protection Agency (EPA) requires orthophosphates to be added to drinking water. The orthophosphates create a barrier on the inside of the pipe, which helps keep pipes from corroding. Unless the orthophosphate barrier is constantly replenished through on-going additives, the barrier will degrade and disappear and the pipes will corrode. Corroded lead pipes allow the lead to leach into the drinking water. Water can be made more corrosive by the addition of other chemicals or a change in pH, so if the orthophosphate barrier is gone, the increased corrosivity means increased lead leaching.

Please review all the curated resources for more background information before teaching this lesson.

PREPARATION

Before starting this activity with students, you will need to conduct a Crowd the Tap test on a residence. It can be your residence or that of a family member or friend. Report your data on **crowdthetap.org**.

TIPS

FOR INFORMAL EDUCATORS

If class time is short, or if using this lesson as part of an informal learning opportunity outside of a formal school day:

- Start with presenting the Crowd the Tap website and look at the data. Show students that there are still lead pipes in use in the U.S., and there is a need to identify where they are.
- From the Explore section, choose an age-appropriate background video or two to illustrate the issues with lead pipes and water.
- If possible, ask participants to do Crowd the Tap testing at home, or conduct the tests yourself and share your data. A group of youth could also conduct this project as service learning outreach in partnership with a neighborhood.

Crowd the Tap is a nationwide project funded by the U.S. EPA and led by North Carolina State University and Virginia Tech.
CrowdTheTap.org

ENGAGE

Using results from the Crowd the Tap citizen science project and other resources, students examine the issue of lead in the water.

1. Introduce your students to Crowd the Tap, a citizen science project. Elicit and record students' prior knowledge and current understanding of lead pipes that carry drinking water. (Note: You do not have to address all misconceptions.) Share your personal concerns about lead pipes and motivations for testing your pipes.
2. Review the Crowd the Tap process up to and including the data reporting.
3. Review the aggregated data. Emphasize that lead in drinking water pipes still exists, even if you did not find lead pipes in your investigation. Scroll down on **crowdthetap.org** to "See What Others Have Reported."
4. Do a think/pair/share or small group to large group discussion about reactions to Crowd the Tap data and findings. Note that lead pipes do not automatically result in lead in the drinking water but lead pipes do mean a higher risk for lead in the water. If necessary, discuss the idea of risk and acceptable levels of risk.
5. Highlight Flint, Michigan, a community that had lead pipes and the lead ended up in the water, with this article: **time.com/4191864/flint-water-crisis-lead-contaminated-michigan**
6. Tell students that they are going to explore how lead from pipes gets into the water and why it matters.

EXPLORE

Through researching curated resources, students explore two driving questions: **Why is lead a concern? How does lead get into the water?**

1. Write the driving questions on the board. In small groups have students research the driving questions, starting with the curated resources below. You will need to help students understand the main ideas from the resources through discussion and writing.
2. Review each of the discrete topics. If time allows, have students create an infographic on how lead is leached to solidify their understanding of the process. This could be a simple 6-step diagram with illustrations and explanations to reinforce the videos above.
3. Explain that students will be putting together all the pieces they have learned in a case study of lead in the water in Flint, Michigan.

EXPLAIN

Driving Question 1: Why is lead a concern?

VIEW How Stuff Works video, "Lead Poisoning" **youtu.be/EGac6S0NLXk**	**COMPREHENSION QUESTION** **Explain how lead poisons your body.** Lead is inhaled or swallowed as dust, and your body absorbs it, just as it takes in nutrients. Lead masquerades as nutrients but cannot perform the same nutrient functions.
VIEW Gross Science/PBS Digital Studios video, "What Does Lead Poisoning Do to Your Brain" **youtube.com/watch?v=76RKSQgduVQ**	**COMPREHENSION QUESTION** **What does lead do to your brain?** Lead prevents the absorption of calcium, which is critical for the production of BDNF, an important brain chemical for brain functioning. The impact is serious for children.
READ EPA article "Basic Information about Lead in Drinking Water," section: "Health Effects of Exposures to Lead in Drinking Water" **epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water#health**	**COMPREHENSION QUESTION** **What are the health impacts of lead?** - Children can experience problems, including behavior and learning difficulties, hyperactivity, slowed growth, hearing problems, and anemia. - Pregnant women can have reduced growth of the fetus and premature birth. - Adults can have increased blood pressure and incidence of hypertension, decreased kidney function, and reproductive problems (in both men and women).

Driving question 2: How does lead get in the water?

ACTIVITY
"Water Treatment for Human Consumption"
nationalgeographic.org/activity/water-treatment-human-consumption

Note: If students are unfamiliar with water treatment and delivery, this activity may help them understand the process.

REVIEW
Compound Chem graphic and article, "The Chemistry Behind Your Home's Water Supply"
compoundchem.com/2016/04/21/water-treatment

COMPREHENSION QUESTION
What happens to water between intake from water source and delivery to home?
Water is treated in multiple ways. Orthophosphates are added to prevent lead from corroding out of the pipes into the water.

READ
EPA article, "Basic Information about Lead in Drinking Water: How Lead Gets into Drinking Water"
epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water#getinto

VIEW
Scientific American video, Corrosive Chemistry, "How Lead Ended Up in Flint's Drinking Water"
scientificamerican.com/video/corrosive-chemistry-how-lead-ended-up-in-flint-s-drinking-water1

READ
PBS WHYY article, "Explainer: Lead pipes can mean bad water, but corrosion control can limit lead's impact"
whyy.org/articles/lead-pipes-can-mean-bad-water-but-corrosion-control-can-limit-leads-impact

COMPREHENSION QUESTION FOR ARTICLES AND VIDEO
How does lead get into the pipes?
Orthophosphates are added to drinking water to keep pipes from corroding, thereby preventing lead from leaching into the water. When orthophosphates are not added, lead can leach out of the corroded pipes. If the water is made more corrosive by a change in pH, that will allow more lead to leach out.

Additional Resource for Chemistry:
American Chemical Society, "The Flint Water Crisis: What's Really Going On?"
acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/2016-2017/december-2016/flint-water-crisis.html

Students are able to explain how lead gets into the water from delivery to tap and to discuss the risk to human health.

1. Using a flipped classroom model or in class, watch this video: **The Science of Flint's Water Crisis**. Allow students to take notes. Provide the transcript to allow them opportunities for additional review.
2. Using their knowledge of water delivery, water treatment, and lead, students work in groups to explain what happened in Flint. Allow them a choice of formats (slides, video, poster, report) to present their information. Content should include:
   - Flint changed its water source.
   - The new water source did not have the corrosion treatment.
   - Additional corrosion was caused by extra chlorides from deicing roads using salt and extra chlorine added to address elevated bacteria.
   - Corrosion allowed lead to leach out through redox reactions.

EXTEND/APPLY

Using their knowledge of lead in water, students discuss the results of the Crowd the Tap data originally presented. This discussion will be informed by the findings from the data. Do students feel they are at risk of being impacted by lead in their community or school? Why or why not? What further information would they like to have?

Possible extensions:

- Read city water reports.

- Invite someone from the city water department to discuss corrosion treatment. If water is not treated for corrosion, find out why.
- Students conduct Crowd the Tap at home, with guidance from CrowdTheTap.org and the "How to Crowd the Tap" student handout. The handout provides summary information for the family and can be signed to show participation.
- If time allows and several students have been able to conduct Crowd the Tap at home, have them present and analyze their data in class. Using a mapping tool, e.g., Google maps, have students label who has what type of pipe and where. They can create a graph showing the variability in pipes, their locations, and the years the homes were built. What patterns does the map show? Are there any areas of concern in their local area?
- Reinforce students' chemistry understanding and relevance to the phenomena with the "Chemistry Connections" worksheet. The answer key is included at the end of this document.

EVALUATE

Students respond to the questions below. Choice of format can be teacher or student driven. The formats may include video response, written essay or short answer questions, poster, narrated presentation or slide show.

1. **Why are lead pipes in use?** *Lead pipes were formerly a popular metal due to malleability and durability. They are expensive to replace.*
2. **Explain why using lead pipes is a concern.** *Lead is a human health concern. Lead can impact organs, including the brain. Lead mimics metals our bodies use, such as calcium and zinc, so we absorb it, but lead harms rather than nourishes.*
3. **How is the risk from lead pipes reduced in water treatment?** *The risk from lead pipes can be reduced by creating a barrier between the pipe and water through the addition of orthophosphates. The orthophosphates create a crusty barrier within the pipe. The orthophosphates have to be continually maintained or else they will corrode off.*
4. **What happened in Flint, Michigan, that made the lead pipes an issue?** *The anti-corrosive agents were not added so lead leached into the water supply. Further complicating the issue were high levels of chloride in the water due to runoff from winter road de-icing using salt and the addition of chlorine to combat high levels of bacteria. These elevated levels of chloride exacerbated corrosion and leaching.*
5. **What do you know about lead pipes in your home, school, or community?** *Answers will vary.*

Take Crowd the Tap Further

Crowd the Tap is looking for **500 households** interested in having a deeper understanding of the water quality in their homes and community. These households, by completing the full set of tests available, will be helping the Crowd the Tap team develop a nationwide research model. The full set of tests includes the following:

- Crowd the Tap
- A low precision water chemistry test strip; you can request by sending an email to **crowdthetap@ncsu.edu**.
- A high precision water quality test for lead from the non-profit Healthy Babies Bright Futures. Go to **hbbf.org/lead-drinking-water** to order. Through a donation program, it is possible to receive the kit for as little as $12.

All of the data collected from these tests can be entered through

Crowdthetap.org.

Standards

NGSS: Chemistry

This activity was designed to serve as phenomena to anchor or apply the teaching of redox reactions and Le Chatelier's principle. It can be used as a part of a storyline that will guide students to achieving the following performance expectations.

- HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.
- HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Environmental Science

This activity supports students in using NGSS science and engineering practices to explore and explain disciplinary core ideas in the context of the cross-cutting concepts. For Advanced Placement Environmental Science, the activity supports the following:

Units

- Land and water use
- Aquatic and terrestrial pollution

Skills

- Explaining environmental concepts and processes
- Applying quantitative methods in solving problems
- Analyzing data, visual representations, and writings

Common Core: ELA/Literacy

- RST.11-12.1. Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- WHST.9-12.2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.
- WHST.9-12.5. Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- WHST.9-12.7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- SL.11-12.5. Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Common Core: Math

- MP.2Reason abstractly and quantitatively
- MP.4Model with mathematics

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CROWD THE TAP

Chemistry Connections

Answer Key

NAME ______________________

CLASS ______________ DATE ______________

Check out these resources* to help you work through the questions below:

Scientific American – Animation
Corrosive Chemistry

ACS Article
The Flint Water Crisis

Chemistry Explained
Chemical Reactions

Let's start with some basic chemistry:

Consult a periodic table (in your science textbook or **here**). Find lead, oxygen, and chlorine on that periodic table. What information can you gather about each of these elements? Complete the chart:

Element	Chemical Symbol	Atomic Number	Group/Family Column Number	Metal or Non-Metal	Determine # of Valence Electrons	Atom's Preferred Charge (Oxidation State)
Sodium	**Na**	**11**	**1**	**Metal**	**1**	**+1**
Calcium	**Ca**	**20**	**2**	**Metal**	**2**	**+2**
Chlorine	**Cl**	**17**	**7 (17)**	**Non-Metal**	**7**	**-1**
Oxygen	**O**	**8**	**6 (16)**	**Non-Metal**	**6**	**-2**
Lead (II) (this is the tricky one)	**Pb**	**82**	**14**	**Metal**	**2, 4**	**+2**

Resource Links:
"Corrosive Chemistry": **https://www.scientificamerican.com/video/corrosive-chemistry-how-lead-ended-up-in-flint-s-drinking-water1**
"The Flint Water Crisis": **https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/2016-2017/december-2016/flint-water-crisis.html**
"Chemistry Explained": **http://www.chemistryexplained.com/Di-Fa/Equations-Chemical.html**
Periodic Table: **https://pubchem.ncbi.nlm.nih.gov/periodic-table**

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1. Why are chemists so concerned about valence electrons?

   They determine the chemical behavior of an atom. Valence electrons are the outermost electrons, most likely to react with surrounding atoms, and thus determine properties of the element.

2. Describe how Na and Cl react. How do you determine its balanced formula? What type of bond is formed between the two?

   Sodium gives up an electron, chloride takes in an electron, two oppositely charged ions form ionic bond.

$$Na^{+1}\,(aq) + Cl^{-1}\,(aq) \rightarrow NaCl\,(aq) \quad \text{or} \quad 2Na\,(s) + Cl_2\,(g) \rightarrow 2\,NaCl\,(s)$$

The reaction of Na and Cl is an energetically or strongly favorable reaction, where reactants form only the product. But some chemical reactions are reversible, which means the reactants react to form products, and the products can fall back apart into the original reactants. These types of reactions reach an equilibrium when the rate of the forward reaction equals the rate of the reverse reaction. This is written in a generic format:

$$AB + C \leftrightarrow A + BC$$

3. If we added more BC to a reaction at equilibrium, explain what you think would happen to the reaction.

   The reaction would shift towards the reactants.

Le Chatelier's Principle indicates that if a chemical reaction at equilibrium is subjected to disruption because of a change in conditions (such as the change in amount of reactant or product), then the reaction will reach a new equilibrium by moving in the direction that offsets the change in condition. This principle connects to our lead in the water supply issue. But before we get to that, let's make sure we know some important concepts that help explain how lead ended up in the water in Flint.

4. Using the resources provided at the top of the page, write a 2-3 sentence description of corrosion of any type of metal pipe.

   Answers will vary but content should come from articles and may include oxidation. Fe metal oxidized to form rust (chemically Fe_2O_3); Copper on Statue of Liberty turned green due to oxidation (due to formation of various Cu oxides (CuO_x) and copper hydroxide $Cu(OH)_x$).

5. List at least three factors that helped increase corrosion in water pipes.

   Answers will vary but evidence should come from articles. Responses might include high chlorine, low pH, and lack of orthophosphate.

6. What happens to the atoms involved during the oxidation part of the reaction? (describe in words)

   Atom's valence or outer electrons are lost.

7. And now, what happens during a reduction reaction? (describe in words)

   Atom's valence electrons are gained.

8. Explain why reduction and oxidation reactions are coupled and known as redox reactions.

   Electrons lost must be transferred and gained by another atom.

Remember Le Chatelier's principle from above? Let's take everything you know so far and apply it. We know that there were high levels of chloride ions in the water, and that the pH of the water was too low. It turns out, pH plays an important role because it disrupts the equilibrium of the chemical reactions between the water and lead pipes. You learned that orthophosphate is added to the water to create a barrier between the lead pipes and the water. Orthophosphate reacts with lead in the pipe to form a crusty barrier that includes lead(II) carbonate ($PbCO_3$). It turns out $PbCO_3$ can dissolve a little in water and sets up an equilibrium that looks like this:

$$\mathbf{PbCO_3}\,\boldsymbol{(s)} \qquad \mathbf{Pb^{2+}}_{\boldsymbol{(aq)}} + \mathbf{CO_3^{\;2-}}_{\boldsymbol{(aq)}}$$

Carbonate reacts with hydrogen ions (H+), removing them from the system and leaving lead ions in the water. If the pH of the water is low, that means there will be lots of H+ available to react with carbonate.

9. What will happen next (based on Le Chatelier's principle) to the concentration of lead ions in the water?

   Lead ions will increase in concentration.

OK, now let's push the learning to the next level. Your teacher might help you with these questions, depending on what you've covered so far.

10. Let's consider the components involved with lead pipe corrosion and water delivery. Some of the major players include the ions chloride, oxide, and lead. For each one, determine the most likely oxidation state that the ions become. Need some help? Check out the Periodic Table link in question 1.

Initial Condition	Ion it becomes	Gain or Loss of electrons to become ion	How many electrons?	Final oxidation state of the ion
Cl_2	**Cl^{-1}**	**gain**	**1**	**-1**
O_2	**O^{-2}**	**gain**	**2**	**-2**
O_2 (+ $2H_2O$)	**4 OH^{-1}**	**gain**	**4**	**-1**
Pb	**Pb^{+2}**	**loss**	**2**	**+2**

11. Chlorine (Cl_2) is added to water as a disinfectant. It can also react with the metal in lead pipes, driving them to become Pb(II). Write the two half reactions and overall reaction for the lead / chlorine redox reaction below.

Oxidation

$$\mathbf{Pb \rightarrow Pb^{2+}_{(aq)} + 2\,e^-}$$

redaction

$$\mathbf{2\,e^- + Cl_{2\,(aq)} \rightarrow 2\,Cl^-_{(aq)}}$$

full redox reaction:

$$\mathbf{Pb_{(s)} + Cl_{2\,(aq)} \rightarrow PbCl_{2\,(s)}}$$

Notice while this is the redox reaction, it is **$PbCl_2$** dissolving that causes the poisoning

$$\mathbf{PbCl_2 \leftrightarrow Pb^{+2} + 2Cl^{-1}}$$

12. Mass is conserved during a chemical reaction. Using your reaction from question 10, write the atomic masses (or molar mass for compounds) above each element in the formula.

207.2g		**70.9g**		**278.1g**	**formula masses**
Pb	+	**Cl_2**	→	**$PbCl_2$**	**reaction**

13. If 0.007 g of chlorine was used to disinfect a liter of water, what maximum amount of Pb(s) would still be able to dissolve into 1 L of solution of $PbCl_2$? Use the above equation to work as a mass to moles back to mass factor label style.

$$0.007\text{g } Cl_2 \left(\frac{1 \text{ mol } Cl_2}{70.9\text{g } Cl_2}\right)\left(\frac{1 \text{ mol Pb } Cl_2}{1 \text{ mol } Cl_2}\right)\left(\frac{278.1\text{g } PbCl_2}{1 \text{ mol Pb } Cl_2}\right) = 0.02045\text{g } PbCl_2$$

14. No amount of lead is good in drinking water, but the EPA has determined that if the level of dissolved Pb remains below 15 mg/L for 90% of houses tested, then no action is legally needed. Would there need to be action taken in the previous problem? (Be careful with the prefix on the regulation.)

Yes, 0.0205 g of lead would dissolve, which is above the action level.

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