



**Tools and Resources**

***“The Shocking Chemistry of Electric Eels”***

October/November 2018

<http://www.acs.org/chemmatters>

**Teacher’s Guide:**



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***“The Shocking Chemistry
of Electric Eels”***

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**Table of Contents**

[Connections to Chemistry Concepts 3](#_Toc524369024)

[Teaching Strategies and Tools 4](#_Toc524369025)

[Standards 4](#_Toc524369026)

[Vocabulary 5](#_Toc524369027)

[Possible Student Misconceptions 6](#_Toc524369028)

[Anticipating Student Questions 7](#_Toc524369029)

[Activities 9](#_Toc524369030)

[References 11](#_Toc524369031)

[Web Resources for More Information 12](#_Toc524369032)

# Connections to Chemistry Concepts

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| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Electrolytes** | The discussion of the electrolytes used in Volta’s initial battery can be used as a practical application to supplement lessons on ions and ionic solutions. |
| **Electrochemistry** | The explanations of voltage and current using a waterfall analogy supports lessons about electrical energy, while the description of the anatomy of Volta’s battery supports lessons about electrochemical cells and batteries. |
| **Activity series** | The selection of materials for an electrochemical cell is based on their ability to lose or gain electrons. The activity series table in this article helps students understand some of the differences between metals. |
| **Intermolecular forces** | During a unit on intermolecular forces, the description of the reaction in the eel’s electrocytes, where each activated cell flips a neighboring cell so the negative side of one cell is adjacent to the positive side of the one next to it, can be used to help students visualize dispersion forces and induced forces. |
| **Conductivity/Properties of matter** | Conductivity is a concept that is covered in most units on the properties of matter. The conductivity of electrolyte solutions in the electric eel can be used as a practical example of one use of these solutions in nature. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:
	+ **ELA-Literacy.RST.9-10.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
	+ **ELA-Literacy.RST.9-10.5**: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
	+ **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.
	+ **ELA-Literacy.RST.11-12.4:** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
	+ **ELA-Literacy.WHST.9-10.2F**: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
	+ **ELA-Literacy.WHST.11-12.1E**: Provide a concluding statement or section that follows from or supports the argument presented.

## Vocabulary

* **Vocabulary** and **concepts** that are reinforced in the October/November 2018 issue:

Food chemistry

Structural formulas

Chemical reactions

Reaction rates

Oxidation & reduction

Distillation

Environmental chemistry

* Consider asking students to read “Open for Discussion: The Human Drive to Explore Space” to learn about the risks of space exploration prior to reading the article “Mars vs. Titan: A Showdown of Human Habitability.”
* Students may become interested in growing crystals to connect chemistry and art after reading the articles on pages 2 and 19.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* The *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

# Possible Student Misconceptions

1. **“Electric eels kill their prey by electrocuting them.”** Electric eels use their electric charge primarily to immobilize their prey as the charge emitted is not sustained long enough to kill the animal. The charge simply causes the muscles in its prey or predator to contract, preventing the animal from moving. If a small fish or animal continues to move, the eel encircles its prey in order to increase the voltage of its emissions. With increased voltage a small fish may be killed. Once the prey or predator is immobilized, the eel can quickly move to swallow the fish or swim away from a predator. In the case of spiny fish, the immobilization prevents the fish from damaging the eel’s mouth, where its lungs are located. Electric eels, unlike true eels, do not have teeth.
2. **“Electric eels are a special class of eels.”** Although the electric eel looks like an eel it is a knifefish and is more closely related to the catfish than an eel. Actually, electric eels are in a class by themselves being the only species in their genus.
3. **“Electric current is the flow of electrons through initially-empty wires.”** Electric current can be compared to the water in your pipes. When you open the faucet, the water that comes out was already in the pipes, it did not come directly from the water treatment facility the moment you opened the faucet. Electric current is the flow of electrons, but those electrons are already in the wire. The electrons themselves move slowly, at a rate of about 1 meter per hour, while the speed at which the electrical energy moves when the circuit is completed is extremely fast.
4. **“No one can survive being electrocuted by an electric eel.”** Being electrocuted by an electric eel is similar to being shocked by an electric fence. It is not pleasant but is generally not life threatening. There have been some reports of persons dying after being shocked by an eel, but the cause of death was drowning after the stunned person fell into the water and could not move. The electric eel can produce a shock up to 860 volts and 1 ampere of current for 2 milliseconds. Due to the short duration of the shock, it is unlikely to be deadly for an adult human. For comparison, atrial fibrillation requires 700 milliamps be delivered across the heart muscle for 30 milliseconds or more in order to shock the heart muscle. The eel cannot maintain its shock for this amount of time.
5. **“The high voltage is what kills you.”** While high voltage is dangerous, it is actually the current that kills. Voltage and current are two different ways of measuring electricity—the flow of electrons in a conductor. Voltage is the force that pushes the electrons through the circuit, while current is the rate of electron flow. The electric eel is an example of high voltage and low current. There can also be circuits with low voltage and high current that may be more dangerous. A dentist’s water jet can be used as an analogy of a high voltage low current circuit. The water pressure in the jet’s stream would be the voltage, while the amount of water ejected is the current. It is unlikely that you would drown while the dentist is cleaning your teeth. An analogy of a low voltage but high current would be a storm drain where a lot of water passes through the drain but at low pressure. If you got swept into a storm drain during a bad storm there is a possibility of drowning.

# Anticipating Student Questions

1. **“Are there any other animals that use electrolocation?”** There are animals that use electrolocation, but not many use it the same way that the electric eel does. The electric eel can generate an electric field to find its prey using electric organ discharges. This is referred to as active electrolocation. The eel has specialized electrosensitive neurons that can detect the direction of any distortions in the field caused by other objects. Most animals that use electrolocation use passive electrolocation. They do not generate the electric fields but have specialized receptors that can detect changes in weak electric fields. Examples of animals that have passive electrolocation are sharks, rays, dolphins, some bony fish, duck-billed platypuses, spiny anteaters, and bees.
2. **“Which is the most dangerous of the electric fish?”** The electric eel is the most dangerous of the electric fish, primarily due to its size. The longest electric eels can get up to 8 feet in length, weigh 50 pounds, and produce an electric discharge of nearly 600 volts.
3. **“Are there any animals that prey on electric eels?”** The electric eel is at the top of its food chain. The only animals that eat electric eels only eat eels that have died. Humans are the only animals that seem to have an interest in catching electric eels.
4. **“Why isn’t the electric eel affected by the electricity it emits into the water?”** That is a good question and the truth is scientists do not know. The mechanism electric eels use to protect themselves from their own charge hasn’t been studied. Some have hypothesized that the eel’s size or something in the eel’s skin protects them from the charge. Also, as the charge is released into the water, it is dissipated and weakened and the large eel wouldn’t be affected. The charge affects the small animals in the water more than it affects larger ones. That being said, the eel can leap out of the water to shock a large crocodile in order to protect itself from being attacked. In cases where the eel leaps from the water, the intensity of the shock increases because it is not being dissipated by the water but is being directed through the animal predator (or hapless bystander).
5. **“Can an electric eel shock a competing electric eel?”** In water,the eel is protected from its own discharge as well as that of other eels, though the protective medium is not clearly understood. Eels have not been observed attacking other eels.
6. **“****How can an element that generally loses electrons lose them to another element that also loses electrons?”** When two metals that generally ionize by losing electrons are used in electrochemical cells, other criteria need to be examined to determine which element will lose electrons, or be oxidized, and which one will gain electrons, or be reduced. Using an activity series like the one in the Rohrig article and in most chemistry texts can help determine this. A cell created with two metals will have the metal higher on the list as its anode (where oxidation or electron loss occurs) and the other metal will be the cathode, where reduction or electron-gain occurs. The element higher on the list will require less energy to lose its outer electrons than the elements below it on the list.
7. **“What is an anode? What is a cathode**?” An anode is the terminal in an electrochemical cell or battery where electrons are lost (oxidation), while the cathode is the electrode where electrons are gained (reduction). In an electric eel, the eel’s head is the cathode and the tail is the anode. When threatened, an eel discharges its electric shock through its chin.
8. **“Do people eat electric eels? One time, I saw eel on the menu of a restaurant my family went to.”** Electric eels are generally not eaten. Their bodies are composed primarily of the three pairs of electric organs with very little edible muscle surrounding them. The eel or brood of eels that you may find in the seafood section are from the true eels and are becoming an expensive delicacy in many countries. They are popular in Japanese and Chinese cuisine.

# Activities

**Labs and demos**

**“Activity Series Lab (Microscale)”:** In this two-part lab, students test samples of Cu, Mg, Fe, Zn, and Sn against solutions of KNO3, Zn(NO3)2, Mg(NO3)2, AgNO3, CuSO4, and distilled water in part one, and they test the same metals in dilute HCl in part two to determine an activity series for the elements involved. (<https://www.auburn.wednet.edu/cms/lib03/WA01001938/Centricity/Domain/1360/GChemLabs/Activity_Series_Lab.pdf>)

**“A Voltaic Pile, the First Battery”:** This is the first lab that follows an introduction to the history of batteries. Multiple lessons and activities involving the student creation of voltaic piles, electrochemical cells, lemon cells, storage cells, and dry-cell batteries are outlined in the work cited here: <http://www.chymist.com/batteries.pdf>.

**Simulations**

**Activity series experiments, virtual labs:** These experiments allow the students to use their results from combining several metals with different ionic solutions to determine an activity series of select metals. (<http://intro.chem.okstate.edu/1515F01/Laboratory/ActivityofMetals/home.html>)

Teacher-developed data tables and class instructions for some of these activities can be found here: <http://www.mrpalermo.com/virtual-lab-activity-series.html>.

**Media**

**“You Do Not Want to Get Tased by This Eel”, (1:59) video, and “Electric Eels Carry All Their Organs in Their Head”, (4:29) video:** These two videos, accessed at the same site, below, describe the unique characteristics of the eel’s anatomy using live footage and diagrams in the first video and showing the capture and examination of an eel in the second video. (<https://www.smithsonianchannel.com/shows/electric-amazon/0/3425708>)

**“It’s True: Electric Eels Can Leap from the Water to Attack”, video (3:22):** Researcher Kenneth Catania discusses Humboldt’s experience with eels leaping from the water to shock the horses and demonstrates how the eel's’ shock is magnified when they leap from the water. (<https://video.nationalgeographic.com/video/news/electric-eels-make-leaping-attacks-vin>)

**Lessons and lesson plans**

**Lemon batteries and electric pickles, demonstration and lesson:** Electrical energy and electrochemistry are explained through the use of the glowing pickle demonstration, followed by PowerPoint presentations and a student challenge to construct a lemon battery. (<http://star.manhattan.edu/UserImage/EA%20Lesson%20Plans/LemonBatteryPickleExperimentLessonPlan.pdf>)

**Building a voltaic pile, lab activity with lessons about energy:** Students explore the Law of Conservation of Energy by reviewing common forms of energy and how they may be converted to other forms of energy. The lesson culminates with a lab activity to build voltaic piles utilizing copper pennies, zinc plated washers, and salt water-soaked cardboard. (<http://www.cpalms.org/Public/PreviewResourceLesson/Preview/128908>)

**Projects and extension activities**

**“Recreate Physics History: Build a Voltaic Pile”, two videos (6:53 and 9:45):** These videos illustrating the history surrounding Volta’s discovery complement the instructions for students to build their own voltaic pile similar to Volta’s first electrochemical battery. <https://www.arborsci.com/cool/recreate-physics-history-build-a-voltaic-pile/>

**“Virtual Chemistry Lab Activity Series”:** This lab activity uses photos of various metals placed in test tubes containing either water, HCl, or a metal salt to help students determine an activity series based on their observations. Students select highlighted elements on a periodic table to view the photos of the reactions in order to draw their conclusions. (<http://www.harpercollege.edu/tm-ps/chm/100/dgodambe/thedisk/series/series.htm>)

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**

In “Tasers”, author Rohrig writes about the effect of a Taser’s electric current on the biochemical messaging system in muscles. As the electric eel’s shock is often compared to the shock from a Taser, these explanations as well as the additional explanations of voltage and current enhance the information in the current article. (Rohrig, B. Tasers. *ChemMatters*. 2012, *30* (2), pp 18–19)

The Teacher’s Guide for the April 2012 *ChemMatters* Rohrig article above provides additional information on electromuscular disruption. A lesson listed there from Teach Engineering, about the electrochemistry of the heart muscle, contains demonstrations that could also be used to demonstrate the action of the ion channels in the electric eel. (<https://www.teachengineering.org/lessons/view/uva_pump_bme0607_less> )

“Drained: The Search for Long-Lasting Batteries” contains explanations about the chemistry of batteries that could supplement those about electric voltage and current in the Rohrig eel article. (Kossakovski, Fedor. Drained: The Search for Long-Lasting Batteries. *ChemMatters*. 2017/18, *35* (4), pp 10–12)

The Teacher’s Guide for the February 2018 *ChemMatters* article above contains links to simulations about electrochemical cell voltmeters and a voltaic cell virtual lab, as well as lessons that use voltaic pile activities.

# Web Resources for More Information

**Electric eel facts**

A source of general information about the electric eel can be found on the Wikipedia site.

(<https://en.wikipedia.org/wiki/Electric_eel>)

Facts about the electric eel and several videos about eels can be found at this site.

(<https://www.mnn.com/earth-matters/animals/stories/8-shocking-facts-about-electric-eels>)

**Electric eel research applications**

“Electric Eel-inspired Devices Could Power Artificial Human Organs” describes some of the research into the development of a type of battery that operates like an electric eel and could be used to power pacemakers, sensors, or even prosthetic organs.

(<https://www.nature.com/articles/d41586-017-08617-3>)

 **“**Designing Artificial Cells to Harness the Biological Ion Concentration Gradient” is a report on the progress of designing cells that operate similarly to electric eel’s electrocytes.

([https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2767210**/**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2767210/))

**Electric eel predator behavior**

“Electric Eels Concentrate Their Electric Field to Induce Involuntary Fatigue in Struggling Prey” thoroughly explains with multiple charts and diagrams how the electric fields generated by an eel and their effects on prey are altered by the way the eel manipulates its long body.

(<https://www.sciencedirect.com/science/article/pii/S0960982215011471>)

**Bioelectricity**

A brief review of bioelectricity and its role in human cells can be found here.

(<https://www.encyclopedia.com/medicine/encyclopedias-almanacs-transcripts-and-maps/bioelectricity>)

This site contains a report about research of eel electrocytes, in hopes of learning how to modify muscle cells to power biodegradable electronics.

(<https://techxplore.com/news/2017-08-bioelectricity-eels.html>)

**Alexander von Humboldt**

“Humboldt’s Gift” is a *New Yorker*article, punctuated with several quotes from the scientist’s books and letters that bring new appreciation for the work of von Humboldt.

(<https://www.newyorker.com/magazine/2015/10/26/humboldts-gift>)

This site contains a summary of von Humboldt’s life and scientific contributions. (<https://www.famousscientists.org/alexander-von-humboldt/>)