AQUARIUS
Education & Public Outreach

# ELECTROLYSIS OF SALT WATER

**Unit:** *Salinity Patterns & the Water Cycle* **I Grade Level:** *High school* **I Time Required:** *Two 45 min. periods* **I Content Standard:** *NSES Physical Science, properties and changes of properties in matter; atoms have measurable properties such as electrical charge.* **I Ocean Literacy Principle 1e:** *Most of of Earth's water (97%) is in the ocean. Seawater has unique properties: it is saline, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic.*

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**Big Idea:** *Water is comprised of two elements – hydrogen (H) and oxygen (O). Distilled water is pure and free of salts; thus it is a very poor conductor of electricity. By adding ordinary table salt (NaCl) to distilled water, it becomes an electrolyte solution, able to conduct electricity.*

**Key Concepts**
- Ionic compounds such as salt water, conduct electricity when they dissolve in water.
- Ionic compounds consist of two or more ions that are held together by electrical attraction. One of the ions has a positive charge (called a "cation") and the other has a negative charge ("anion").
- Molecular compounds, such as water, are made of individual molecules that are bound together by shared electrons (i.e., covalent bonds).
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**Essential Questions**
- What happens to salt when it is dissolved in water?
- What are electrolytes?
- How can we determine the volume of dissolved ions in a water sample?
- How are atoms held together in an element?

**Knowledge and Skills**
- Conduct an experiment to see that water can be split into its constituent ions through the process of electrolysis.
- Prepare and experiment with a 10% salt solution to better understand the process of ion exchange.
- Discuss and research the "softness" and "hardness" of water.
- Use the periodic table to identify elements and learn their characteristics.

**Prior Knowledge**
- Define the difference between ionic and molecular compounds.
- Salt consists of sodium (Na) and chloride (Cl).
- Water is a tiny V-shaped molecule with the molecular formula $H_2O$.
- A basic understanding of how a battery works.
- Atoms are made of a positive nucleus surrounded by negative electrons.
- An atom’s electron configuration, particularly the outermost electrons, determines how the atom can interact with other atoms.
- All matter is made up of atoms.
- Atoms of any element are alike, but different from atoms of other elements.

**Common Preconceptions**
- Students may think - **“Water is a good conductor of electricity.”** Water is a very poor “conductor”

of electricity. (The ionization constant for water is very small.) The reason it is dangerous to insert a light bulb while standing in a puddle of water is that water is a great solvent for ionic compounds. Tap water and fresh water typically contain dissolved ions in sufficient concentrations to enable the solution to be conductive. However, ions in solution carry the charge and are thereby responsible for the current, not the water itself.

- Students may think - **"Electrons can flow through solutions."** In "conduction of electricity" through solutions, electrons themselves do *not* pass through the solutions. Rather, charge balance is maintained in the solution by movement of cations and anions toward the electrodes where charge transfer takes place at the solution interface.

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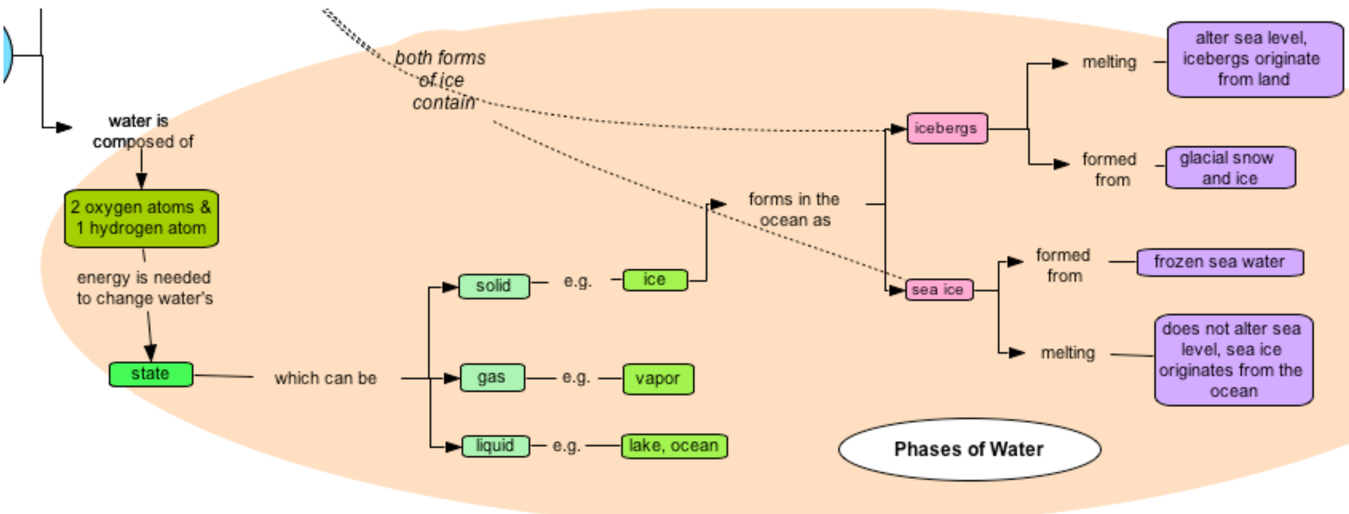
**Concept Map:** This lesson and activity relates to the branch "Phases of Water" from the comprehensive Aquarius Concept Map – Water & its patterns on Earth's surface.

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**Background:**

In chemistry, **electrolysis** is a method of separating bonded elements and compounds by passing an electric current through them. An ionic compound, in this case salt, is dissolved with an appropriate solvent, such as water, so that its ions are available in the liquid. An electrical current is applied between a pair of inert electrodes immersed in the liquid. The negatively charged electrode is called the cathode, and the positively charged one the anode. Each electrode attracts ions which are of the opposite charge. Therefore, positively charged ions (called cations) move towards the cathode, while negatively charged ions (termed anions) move toward the anode. The energy required to separate the ions, and cause them to gather at the respective electrodes, is provided by an electrical power supply. At the probes, electrons are absorbed or released by the ions, forming a collection of the desired element or compound.

One important use of electrolysis is to produce hydrogen. The reaction that occurs is $2H_2O(aq) \rightarrow 2H_2(g) + O_2(g)$. This has been suggested as a way of shifting society towards using hydrogen as an energy carrier for powering electric motors and internal combustion engines. Electrolysis of water can be achieved in a simple hands-on project, where electricity from a battery is passed through a cup of water (in practice a saltwater solution or other electrolyte will need to be used otherwise no result will be observed). Electrolysis of an aqueous solution of table salt (NaCl, or sodium chloride) produces aqueous sodium hydroxide and chlorine, although usually only in minute amounts. NaCl(aq) can be reliably electrolysed to produce hydrogen. Hydrogen gas will be seen to bubble up at the cathode, and chlorine gas will bubble at the anode.

**Faraday's law of electrolysis** states that:

- The mass of a substance produced at an electrode during electrolysis is proportional to the number of moles of electrons (the quantity of electricity) transferred at that electrode
- The number of Faradays of electric charge required to discharge one mole of substance at an electrode is equal to the number of "excess" elementary charges on that ion

These two statements are often considered as separate laws: Faraday's 1st and 2nd laws of electrolysis.

*Background source – Wikipedia*
*http://en.wikipedia.org/wiki/Electrolysis*

**Materials:** *Periodic Table, table salt, distilled water, measuring apparatus; Per Student Group: 9-Volt battery, two electrodes (e.g., copper strips or two #2 pencils each sharpened at both ends), electrical wire, glass beakers or ceramic saucers, electrical tape (optional)*

**Preparation:** *"The Nature of Salt" is a good preparatory activity to acquaint students with the ionic bonds that occur between Na+ and Cl- ions. Lab Safety Reminder – Students should wear goggles at all times during the experiment process. All basic lab safety guidelines for your classroom/lab should be followed.*

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**Activity**

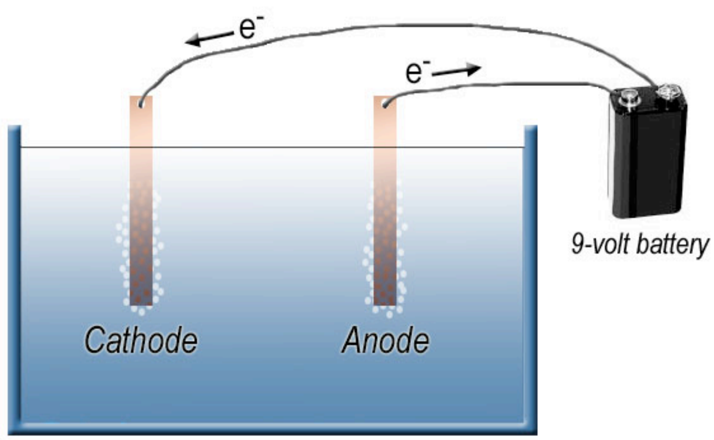
- Have the students read the "Background" section (above) and then find hydrogen and oxygen on a Periodic Table. If students are not already familiar with the general relationship between an element's Periodic Table Group Number and its tendency to gain or lose electron(s), have them research this topic. The relevant Groups for the elements H and O:
  - ***Group 1 (or I) Elements*** – Have one electron in their outer shell. Each element in this group has a tendency to lose a single electron to form a singly charged positive ion. Other than **Hydrogen**, the other elements in this group are known as "Alkali Metals": Lithium, **Sodium**, Potassium, Rubidium, Cesium, and Francium. ***Hydrogen is not metallic*** *and thus, on some Periodic Tables, is shown apart from the Group 1 elements altogether.*
  - ***Group 16 (or VIA) Elements*** **–** Have six electrons in their outer shell. Each element in this group has a tendency to gain two electrons to form a doubly charged negative ion. Elements in this group include **Oxygen**, Sulphur, Selenium, Tellurium, and Polonium. These are known as "Chalcogens" or the "Oxygen family." Their compounds are often called "ore formers."
- This exercise should help students understand why the chemical formula for water is $H_2O$. However, they should also understand that hydrogen and oxygen occur in various ionic forms:
  - Hydrogen can be a cation (i.e., positively charged as H+) or, less commonly, an anion (i.e., negatively charged H- known as a "hydride").
  - Oxygen can be a doubly charged anion called an "oxide" (i.e., $O^{2-}$). In addition, oxygen is often paired with a single hydrogen ion to form a "hydroxide" anion (i.e., OH-).
- Water is an example of a "molecular compound." Atoms in a molecular compound are bound together by shared electrons (i.e., covalent bonds). Water can be split into its constituent elements by passing an electrical current between the positive and negative poles of a battery that is immersed in water. This process is called "electrolysis"; however, rather than splitting water into pure hydrogen and pure oxygen, water molecules naturally split into H+ and OH- ions.
- If you do not conduct the preparatory experiment "The Nature of Salt," review with students the ionic bonds involved in the formation of NaCl. Guided by the Periodic Table, ask them to determine the ionic charge of sodium (Na+) and chlorine (Cl-) in solution.
- Students will prepare a percent composition by mass, specifically a 10% salt solution. Write the following sentence on the board: "Percent composition by mass is the mass of the solute divided by the mass of the solution (i.e., mass of the solute plus mass of the solvent), multiplied by 100."
  - What is the solute? (*Table salt or sodium chloride*)
  - What is the solvent? (*Distilled water*)
- Within a group discussion, come up with the equation used to calculate the mass of salt needed to

be added to water to make a 10% salt solution:

$$\left(\frac{\_\_\_\_\_ \text{ grams of NaCl}}{\_\_\_\_\_ \text{ grams of NaCl} + \_\_\_\_\_ \text{ grams of water}}\right) \times 100 = 10\% \text{ NaCl solution}$$

(One correct ratio is 10 grams of NaCl and 90 grams of water)

- Connect the electrodes to the + and - terminals of a 9-volt battery. Place the other ends of the electrodes in the 10% salt solution. See diagram below. Gas bubbles will appear on the immersed electrodes.




Set-up for electrolysis experiment

- What to expect:
  - As the electricity from the battery passes through and between the electrodes, the water splits into hydrogen and chlorine gas, which collect as very tiny bubbles around the electrode tips.
  - Hydrogen collects around the cathode and chlorine gas collects around the anode.
  - How can you get chlorine from H2O? Sometimes in experiments, a secondary reaction takes place. This is what happens in this experiment.
  - Oxygen is not given off in this experiment. That's because the oxygen atoms from the water combine in the liquid with the salt to form hydroxyl ions. Salt's chemical formula is NaCl - sodium chloride. The chorine gas is from the chloride in the salt. The oxygen in the hydroxyl ions stay in the solution. So what is released in this reaction is not oxygen but is chlorine gas that collects around the electrode tip.
  - In real electrolysis systems, a different solution is used and higher levels of electricity help to split the water molecules into hydrogen and oxygen without this secondary reaction.
- OPTIONAL: If you have an ampmeter that can be set to the microamp scale, you can begin with pure distilled water and gradually add salt to the liquid. As you add more salt to the solution, movement of the needle will indicate increased current flow. The conductivity of a solution is proportional to the concentration of ions in the solution.
- Ask the students: "Which ions will move towards the cathode?" *(Cations, positively charged ions such as Na+ and H+, will move towards the negatively charged cathode.)* "Which ions will move towards the anode?" *(Anions, negatively charged ions such as Cl- and OH-, will move towards the positively charged anode.)* Have the students draw a diagram of the experiment set-up (i.e., similar to figure in the "Background" section). On their diagram, indicate which ions are located near the cathode and the anode.
- As a group, discuss the composition of the gases that appear at the cathode and the anode. If needed, write the following ionic equations for the electrolysis of NaCl solution on the board:

$2Cl^- \Rightarrow Cl_2 + 2e^-$

$2H_2O + 2e^- \Rightarrow H_2 + 2OH^-$

- The upper equation shows the oxidation (i.e., loss of electrons from an atom) at the anode and release of chlorine gas (i.e., $Cl_2$). *NOTE: Cl- is easier to oxidize than water, thus the product formed at the cathode is chlorine gas.*
- The lower equation shows the reduction (i.e., gain of electrons by an atom) at the cathode and release of hydrogen gas (i.e., $H_2$). *NOTE: Water is easier to reduce than Na+ ions, thus the product formed at the cathode is hydrogen gas.*
- Pose the question: "Given the two equations (above), what is the ionic equation for the overall reaction?" ($2Cl^- + 2H_2O \Rightarrow Cl_2 + H_2 + 2OH^-$)

**Assessment / Questions**

- Ask the students: "Why did the salt make the water more conductive to electricity?" *(The molecules of salt dissociate into ions of opposite charges. It is the ions that render the water conductive to electricity. In our experiment, the Na+ and Cl- ions made it possible for the distilled water to conduct electricity.)*
- Ask the students: "Would solid NaCl conduct electricity?" *(No. In a solid compound the Na+ or Cl- ions are strongly attracted to each other; these ionic bonds cannot be broken by an electrical current.)*
- "Would molten NaCl conduct electricity?" *(Yes. In liquid form, the ionic bond between the Na+ and Cl- ions is weakened and thus can become mobile and conduct electricity.)*
- "Would tap water conduct electricity?" *(Yes. There are enough ions in tap water to conduct electricity.)* Ask the students if they have heard the terms "soft water" and "hard water." Ask them to discover what types of ions are usually present in "hard water" *(calcium and magnesium).* Explain that "water softening" is major industry and ask if they can list reasons why this is the case. *(Hard water requires more soap and detergent for laundering, cleaning and bathing because suds do not form well. The reaction between soap and hard water results deposits that make fabrics feel harsh and leave water spots on dishes and utensils. Mineral scale from hard water builds up in hot water appliances and industrial boilers, reducing energy efficiency and shortening appliance and equipment life.)*
  - An independent research project could be assigned that focuses on the water softening process. A great website for this is the "Salt Institute" (http://www.saltinstitute.org).
- OPTIONAL: To access an animation depicting how ionic compounds such as NaCl dissolve in water, visit Northland College (Minnesota)'s Department of Biology webpage (http://www.northland.cc.mn.us/biology/Biology1111/animations/dissolve.html).
- OPTIONAL: To access an interactive animation depicting the interaction of ice, water, and a solute (e.g., salt), visit the "General Chemistry Online!" webpage, "Why does salt melt ice?" (http://antoine.frostburg.edu/chem/senese/101/solutions/faq/why-salt-melts-ice.shtml).
  - Be sure to raise and lower the temperature and "add solute" by clicking on the banner below the "dancing" water molecules. Ask students to explain how this animation relates to their experiment results.

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**Vocabulary**

- **anode:** A positively charged electrode.
- **atom:** A chemical unit, composed of protons, neutrons, and electrons, that cannot further break down by chemical means.
- **cathode:** A negatively charged electrode.
- **compound:** A pure substance composed of more than one element.
- **conductor:** A substance or medium that conducts heat, light, sound, or especially an electric charge.
- **covalent bond:** A chemical bond that involves sharing of electron pairs.
- **electrode:** A solid electric conductor through which an electric current enters or leaves an electrolytic cell.
- **electron:** A negatively charged subatomic particle with a mass of 0.00055 atomic mass units (AMU). By definition, one AMU is one-twelfth the mass of a carbon-12 atom.
- **ion:** A charged particle.
- **ionic bond:** An electrostatic interaction between a cation (+ charged ion) and an anion (- charged ion).

- **molecule:** A pure substance which results when two or more atoms of a single element share electrons, for example $O_2$. It can also more loosely refer to a compound, which is a combination of two or more atoms of two or more different elements, for example $H_2O$.
- **oxidation:** The loss of electrons by a compound or ion.
- **reduction:** The gain of electrons by a compound or ion.

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**Original source:** *Adapted with permission from the Salt Institute's activity "Salt: The Essence of Life" (http://www.saltinstitute.org); Glossary definitions from "EverythingBio.com"*
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