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The birth of electrochemistry: building a simple voltaic pile

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Stacking up: use common household items like coins and paper to explore one of the most significant scientific discoveries of the 19th century.

This activity was presented at the Science on Stage Festival 2024.

The focus of this project is to learn about batteries by building small devices capable of generating electrical energy using common materials, such as coins, aluminium foil, and paper towels. This process will mirror the creation of Alessandro Volta's famous voltaic pile from the early 1800s. A historical narrative on the debate between the Italian scientists Volta and Galvani sets the stage,[1–4] and the activities culminate with students building their own functional devices.

These activities are suitable for high school students aged 15–18.

Volta battery at the Tempio Voltiano museum, Como
Image: GuidoB/Wikipedia, CC BY-SA 3.0

Activity 1: Exploring the birth of electrochemistry

This activity serves as an introduction to electrochemistry by exploring the historical debate between Alessandro Volta and Luigi Galvani on the nature of electricity. This not only helps students understand the scientific context of the time, but also highlights the evolving nature of scientific inquiry and the importance of evidence in shaping our understanding of the natural world.

The debate

The debate originated in the late 18th century when Luigi Galvani observed muscle contractions in frogs' legs in response to electrical stimuli, leading him to propose the idea of 'animal electricity'. Alessandro Volta, however, challenged this theory, arguing that the observed phenomenon was due to the contact between different metals, rather than an intrinsic property of the living tissue.

This activity takes approximately 90 minutes.

If time or suitable facilities are not available, the activity could be assigned as a home project, allowing students to work at their own pace while still following the suggested guidelines. Students are free to choose their own research materials and presentation formats.

Materials

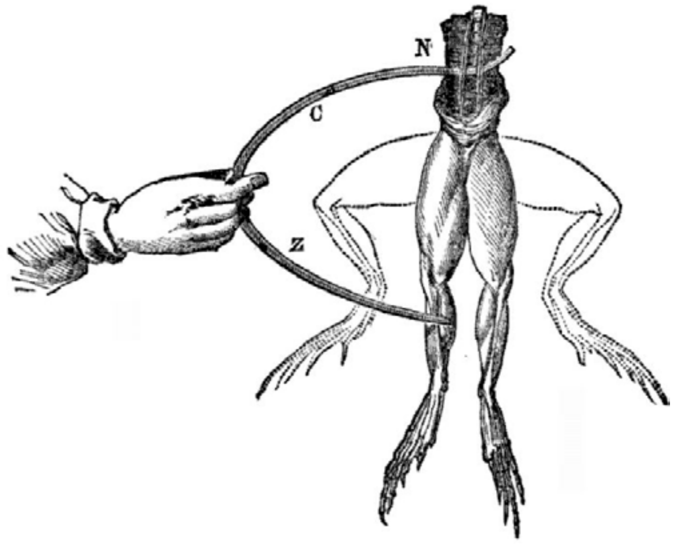
- A multimedia room with internet access
- An old 10 000 lire banknote, or any other stamp, image, or monument featuring Volta (e.g., this famous painting where Volta presents his invention to Napoleon)

An old 10 000 lire note, showing Alessandro Volta
Image: Facquis/Wikipedia, CC BY-SA 4.0

Procedure

1. Begin by showing students an old 10 000 lire banknote or other image featuring Alessandro Volta, and ask if they recognize him.
2. Prompt students to conduct a brief historical research project on the late 18th century debate between Volta and Galvani, concerning the nature of electrical phenomena. No specific materials are required, as the students create their own. To help students focus their research and structure their findings, provide the following guiding questions:
   - What were the main observations and conclusions of Luigi Galvani regarding animal electricity?
   - How did Alessandro Volta's perspective differ, and what experiments did he perform to support his ideas?
   - What role did the scientific context of the late 18th century play in shaping the debate?
   - What were the main points of contention between Volta and Galvani?
   - Who was considered 'right' at the time, and why?
   - How do modern scientific understandings validate or refute the conclusions drawn by Volta and Galvani?

   This approach offers a clear framework for students, while still allowing them the freedom to explore creatively.
3. At the end, the teacher evaluates whether the students successfully achieved the learning objectives.

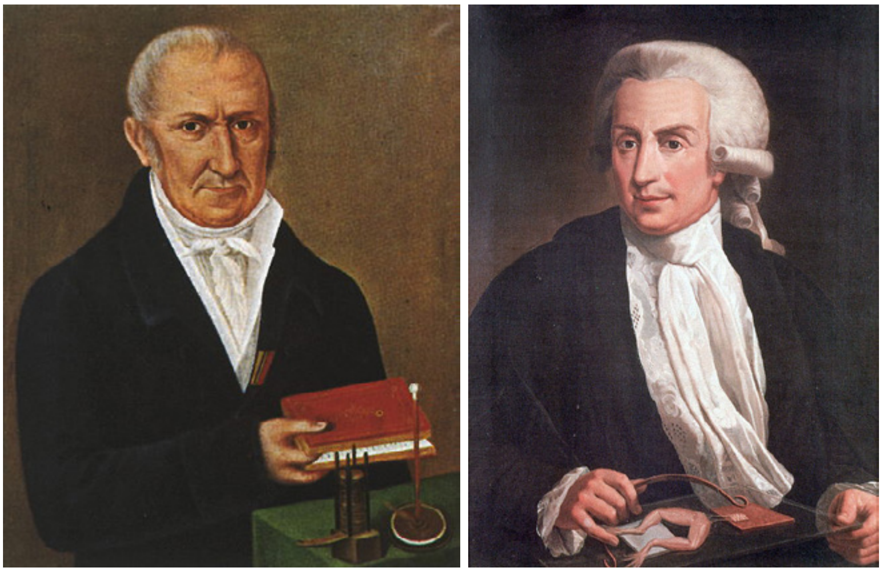


Galvani's famous experiment: electrodes touch a frog, and the legs twitch into the upward position
Image: JohnBad/Wikipedia, Public Domain

Activity 2: Analyzing or roleplaying the historical debate

In this activity, students are encouraged to argue the two sides of the historical debate in either a presentation or role-playing context. By engaging with the historical context and presenting arguments, students will develop skills in critical thinking, public speaking, and collaboration, while gaining an appreciation for the foundations of electrochemistry.

The teacher can organize the discussion in one of two formats, depending on class size and objectives: a scientific talk or a structured debate. Both methods emphasize active learning, debate, and inquiry-based exploration.



Battling giants: Alessandro Volta (left) and Luigi Galvani (right)
Images: A. Volta: Tohma/Wikipedia, Public Domain. L. Galvani: Ctac/Wikipedia, Public Domain

This activity takes approximately 90 minutes, including research, debate preparation, and discussion.

Materials

- The information and research materials from Activity 1
- Access to computer presentation tools or flipcharts and writing materials
- Optional: Galvani and Volta infosheet

Procedure

Scientific-talk format (small-group presentations)

1. Divide the students to work in small groups (maximum of 4 students per group) to conduct additional research on the perspectives of Volta and Galvani.
2. Instruct each group to prepare a short presentation on the Volta/Galvani debate to share with the entire class. Alternatively, assign the groups to present one side of the debate or the other, as if they were Volta or Galvani presenting their findings at a gathering of scientists.
3. During their presentation, each group explains their findings, focusing on the scientific arguments, historical context, and the significance of scientist's perspective.
4. At the end of each group's presentation, the class engages in a question-and-answer session, allowing other students to ask questions about the findings.
5. The teacher can evaluate the presentations based on quality and relevance of the material presented, clarity of the exposition, scientific accuracy, and appropriate use of scientific terminology.
6. The teacher may optionally incorporate anonymous peer feedback to foster collaborative learning and critical reflection.

Structured-debate format (roleplay with a moderator)

1. The class is divided into two groups, with one group assigned to defend Volta's position and the other defending Galvani's views.
2. Roles and structure: within each group, students decide whether to focus on being the lead spokesperson (representing the scientist's position directly) or supporting members who argue specific points or ideas.
3. Explain the debate format: the debate is structured in timed intervals (similar to a televised political debate) to ensure that all students have the opportunity to contribute and that the discussion remains focused.
4. Allow students time to combine/refine their research from Activity 1 and prepare their arguments.
5. Assign one group to start. Each group takes turns presenting arguments and responding to points raised by the opposing side. The teacher acts as the moderator, managing the timing of each segment, asking guiding questions when necessary, and ensuring that both sides maintain a respectful and focused dialogue.
6. The debate concludes with a final summary from each group, reinforcing the central concepts and arguments.

Discussion

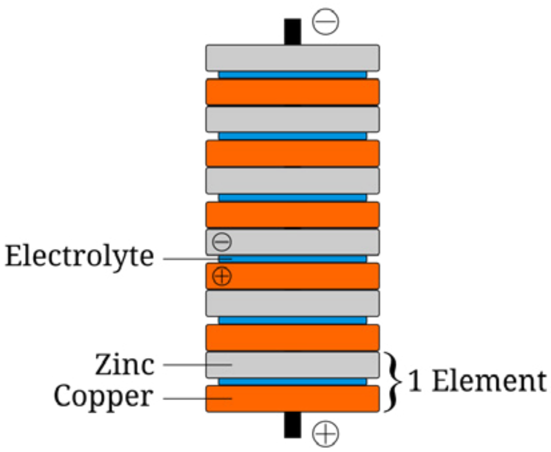
After the debate, the teacher can clarify how, in light of modern scientific understanding, both Volta and Galvani had valid perspectives, illustrating how different viewpoints can reveal multiple aspects of the same phenomenon. The Galvani and Volta infosheet can be used as a basis for this.

Activity 3: Building a simple voltaic pile

In this activity, students explore the basics of electrochemistry by constructing a simple voltaic pile using coins, aluminium foil, and paper towels. This experiment allows students to understand how chemical energy is converted into electrical energy, laying the foundation for more advanced discussions about batteries and energy storage.

Learning objectives

- Understand the principles behind the voltaic pile and redox reactions.
- Gain practical skills in assembling and testing an electrochemical cell.
- Recognize the connections between historical scientific discoveries and modern technologies.



A scheme of a voltaic pile. In this activity, aluminium is used rather than zinc.

Image: Borbrav/Wikipedia, CC BY-SA 3.0

The activity takes approximately 60 minutes: 20 minutes for preparation and setup, 20 minutes for the construction and testing of the pile, and 20 minutes for discussion and measurements.

Materials

- euro 5 cent coins (12 coins)
- Aluminium foil roll (1 m)
- Kitchen towel (2 sheets)
- 5mm light-emitting diode (LED; it is essential that it is red or white)
- 5 mm thick white polystyrene foam sheet (10 cm × 10 cm)
- Bamboo toothpicks (5 pieces)
- Digital multimeter/voltmeter (1)
- Marker and scissors for cutting the discs
- Optional: How it works infosheet

A note on suitable coins

While this activity uses euro 5 cent coins for their copper content, any small copper coins can be used as a substitute. For example, pennies from the USA or UK; preferably those minted before 1992 in the UK or before 1982 in the USA, as they contain a higher percentage of copper. The key is to ensure that the coins have a sufficient copper surface to act as the cathode in the voltaic pile.

Procedure

Preparation:

1. Prepare the electrolyte solution: create a saturated solution by dissolving NaCl (salt) in warm water until no more dissolves. If more convenient, the teacher or technician can prepare this before the lesson.
2. Clean the coins: soak the coins for about 10 minutes in a mixture of water, salt, and lemon juice or vinegar. Rinse under running water and dry thoroughly. If any residue remains, clean with a hard eraser.
3. Cut the discs: cut aluminium foil and paper-towel discs to match the size of euro 5 cent coins.

Assembly:

4. Place a 5 cm strip of aluminium on a 10 cm × 10 cm square of polystyrene, then place a coin on top, and secure it with 2–3 toothpicks to prevent movement.
5. Soak a paper-towel disc in the electrolyte solution and place it on the coin, followed by an aluminium disc. This forms the first part of the galvanic cell.
6. Continue stacking additional layers in the same order: coin–paper–aluminium. Ensure each layer contacts only the previous and next layers to avoid short-circuiting.

Image courtesy of the author

7. Stop after stacking about 10–12 layers.
8. Measure the voltage across the pile using a multimeter by placing the probes at the ends of the pile (1.5 V).

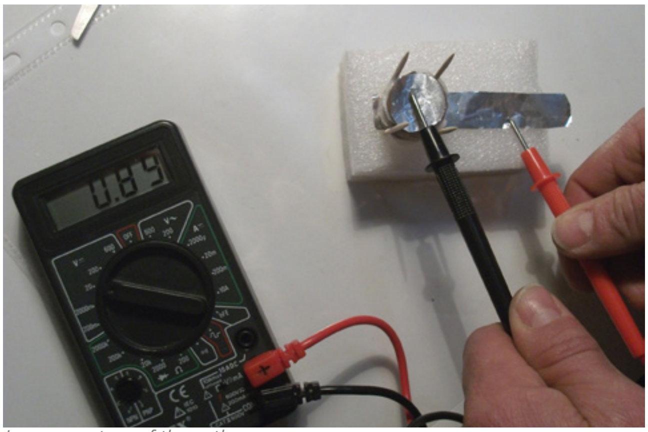


Image courtesy of the author

9. Try lighting an LED, adjusting for the correct polarity by reversing the LED if necessary.
10. Increasing voltage: if multiple groups have built piles, connect them in series by linking the bottom of one pile to the top of another, increasing the total voltage output.[5]

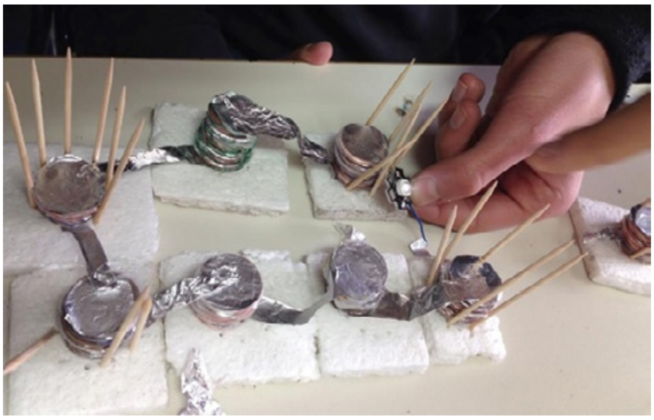


Image courtesy of the author

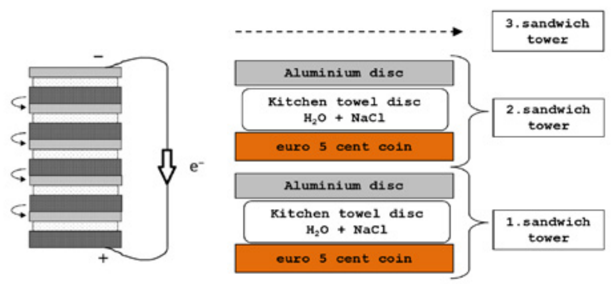
How it works

A battery converts chemical energy into electrical energy through **spontaneous redox reactions.**

The following are essential elements for electricity production:
Anode (–): site of oxidation (loss of electrons)
Cathode (+): site of reduction (gain of electrons)
Salt bridge: contains an electrolyte that facilitates the free movement of positive and negative ions
Electrons flow from the anode to the cathode via a conductive wire.

The composition of the battery constructed is as follows: anode, aluminium; cathode, oxygen; electrolyte, water and NaCl solution; this is the representation of a prototype of an air/aluminium battery.

The voltaic pile and the half equations for each electrode, along with the overall balanced reaction. Tip: It can aid comprehension for some students to write the products of the cathode half equation as two sets of $2OH^-$ instead of $4OH^-$.



$4 \mid Al + 3OH^- \longrightarrow Al(OH)_3 + 3e^-$ Anode (–)

$3 \mid O_2 + 4e^- + 2H_2O \longrightarrow 4OH^-$ Cathode (+)

$4Al + 3O_2 + \cancel{12e^-} + \cancel{12OH^-} + 6H_2O \longrightarrow 4Al(OH)_3 + \cancel{12e^-} + \cancel{12OH^-}$

$\mathbf{4Al + 3O_2 + 6H_2O \longrightarrow 4Al(OH)_3}$

Image courtesy of the author

Discussion

To help students start thinking about the fundamental principles shared by all batteries, the teacher can introduce some leading questions:

- What materials did you use to build the voltaic pile?
- Did you notice any specific role for each material?
- Why do you think the electrolyte solution is necessary?
- What do you think happens to the electrons in the circuit you created?
- How do you think this pile relates to the modern batteries we use every day?
- Did you observe any changes in the appearance of the coins, such as darkening? Why do you think this happened?

Through discussion and guided exploration, students will uncover that the darkening of the coins is due to chemical reactions at the electrode surfaces, specifically oxidation. This observation reinforces the idea that redox reactions are at the core of how batteries generate electricity.

It is essential to highlight that, although Alessandro Volta invented a device that revolutionized science and technology, he was never able to provide an effective explanation of how it worked. This is understandable, given that the discovery of the electron was still 100 years away. Despite this, modern batteries, even the most complex, operate on the same basic mechanism, involving an anode, a cathode, and a salt bridge.

Conclusion

Constructing a voltaic pile provides a wealth of opportunities for reflection and to link to curriculum topics.

The primary discipline involved is electrochemistry, focusing on core concepts such as energy transformation, oxidation–reduction reactions, and electrical circuits. Additionally, the invention of the voltaic pile followed shortly after Galvani's death and was a significant development in the broader scientific debate about the nature of animal electricity. The research conducted by Volta and Galvani laid the foundation for modern electrophysiology.

The voltaic pile was crucial for chemistry, enabling the decomposition of numerous substances (electrolysis) and leading to the discovery of new chemical elements, such as the separation of water into hydrogen and oxygen. In physics, the discovery of the magnetic effects of an electric current paved the way for the invention of electric motors and dynamos (Faraday) and the formulation of electromagnetic field theory (Maxwell). The voltaic pile enabled countless scientific explorations, leading to devices such as light bulbs, dynamos, telegraphs, radios, and radars.

Furthermore, in 1818, Mary Shelley published *Frankenstein*, which tells the story of an inanimate creature brought to life by electrical discharges, likely inspired by the Volta–Galvani debate. The themes of this work are still relevant. Should science have limits? What is life? Can death be conquered? Literature, therefore, serves as a means to decode reality, including scientific realities. «

References

[1] Piccolino M, Bresadola M (2003) Rane, Torpedini e scintille. BollatiBoringhieri. ISBN: 9788833914701 (Italian language)

[2] Piccolino M (2000) 'Anno 2000: Volta elettrofisiologo 200 annidopol'invenzionedella pila voltaica. *Naturalmente* **13**: 6–15. (Italian language)

[3] An article on the discovery of bioelectricity: https://cerebromente.org.br/n06/historia/bioelectr2_i.htm

[4] A summary of the debate between the Italian scientists Volta and Galvani: https://www.whipplemuseum.cam.ac.uk/explore-whipple-collections/frogs/frogs-and-animal-electricity

[5] Simple experiments with a Volta battery (Italian language): https://www.reinventore.it/approfondimenti/scatolab-10-la-pila-di-volta

[6] Bharti R et al (2024) Aluminum–air batteries: current advances and promises with future directions. *RSC Advances* **14**: 17628–17663. doi: 10.1039/d4ra02219j

Resources

- Explore the life and experiments of Alessandro Volta (Italian language)
- Watch these videos on the Volta/Galvani debate (in French and Italian languages):
  - https://www.youtube.com/watch?v=6K22mAnjm7M
  - https://www.youtube.com/watch?v=x-uIkifAg7A
  - https://www.youtube.com/watch?v=NxgcjhvS-c0
- Try some simple experiments using toilet paper: Stamenov N (2024) Science in a toilet-paper roll. *Science in School* **70**.
- Use baker's yeast to demonstrate biofuel cells in the classroom: Grandrath R, Bohrmann-Linde C (2023) Simple biofuel cells: the superpower of baker's yeast. *Science in School* **66**.
- Build a solar cooker and learn about the thermoelectric effect with Peltier modules: Mancini P (2023) Cooking with sunlight and producing electricity using Peltier modules. *Science in School* **61**.
- Enhance your students' understanding of electrolysis using microscale chemistry techniques: Worley B, Allan A (2022) Elegant electrolysis – the microscale way. *Science in School* **60**.

- Discover some low-cost physics experiments to try out in your own classroom: Gregory M, Varnica G, Lazos PT (2022) My favourite experiments – connecting teachers and ideas. *Science in School* **58**.
- Engage your students and demonstrate fundamental physics with everyday objects: de Winter J (2022) Physics with everyday objects: springy sweets, a universe in your pocket, and drawing circuits. *Science in School* **56**.
- Try this role-playing activity to understand how research projects are funded and the importance of basic research: McHugh M et al. (2022) What is it good for? Basic versus applied research. *Science in School* **55**.
- Teach about electromagnetism using an induction hob: André P, Bastos AR, Ferreira R (2021) Faraday's law of induction: from classroom to kitchen. *Science in School* **52**.
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- Discover Xcool Lab for an inspiring experience at the European XFEL: Aretz S (2023) Xcool Lab at European XFEL: a place to spark students' scientific curiosity. *Science in School* **70**.

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