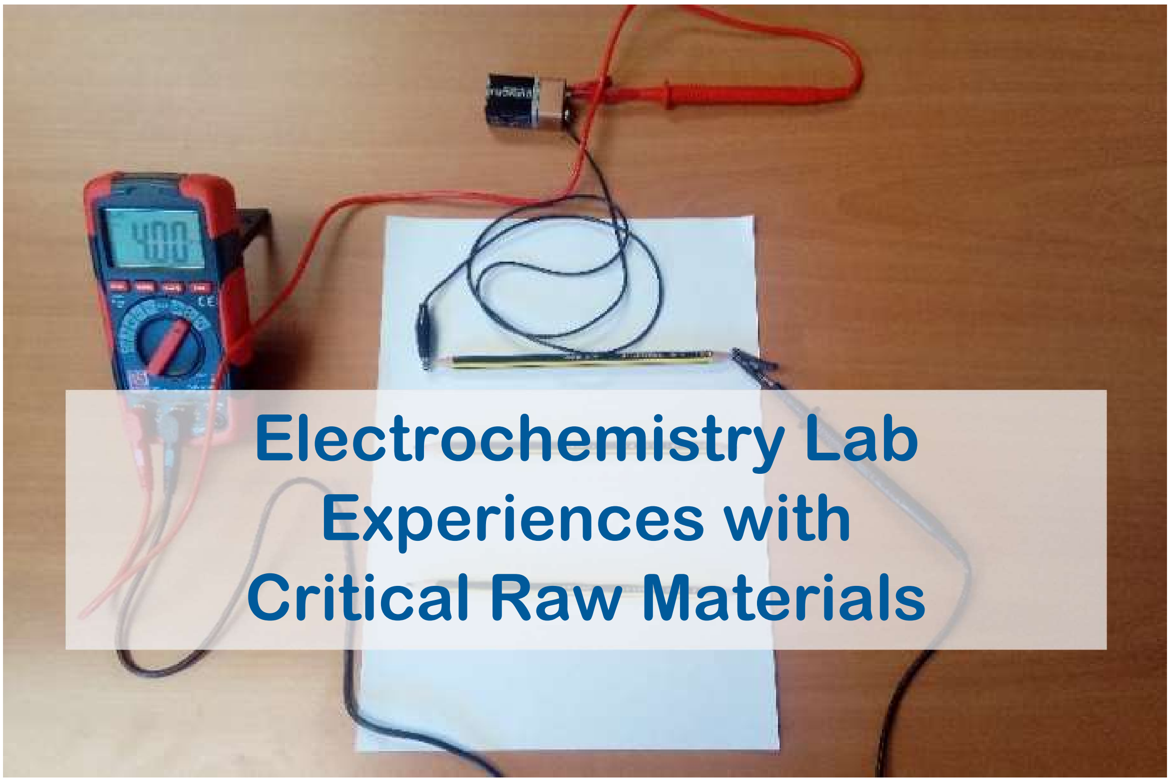
Teachers' Card



Electrochemistry Lab Experiences with Critical Raw Materials

Index

EIT RawMaterials is supported by the EIT, a body of the European Union

General Introduction

This toolkit will give the students the opportunity to study electrochemical reactions, as well as exploring hydrogen's role in the green economy and graphite, which is one of the most promising materials of the future.

The targeted audience are students from 15 to 18 years old, as it is advisable that they have some physico-chemical and technological background.

Electrochemistry allows to describe processes such as the construction and operation of batteries, the spontaneity of oxide-reduction reactions, electrodeposition or electroplating and corrosion of metals.

The toolkit is organized into two lab activities. In the first one, students will check the high conductivity capacity of graphite, being capable of producing water electrolysis and, in addition, they will examine the relationship between lead graphite composition and its electrical resistance applying Ohm's law. In the second one, they will learn different ways of generating energy and stimulate their creative thinking by emulating a battery.

Key words:

Conductivity, Galvanic cell, Graphite, Hydrogen, Water electrolysis.

Extended background information

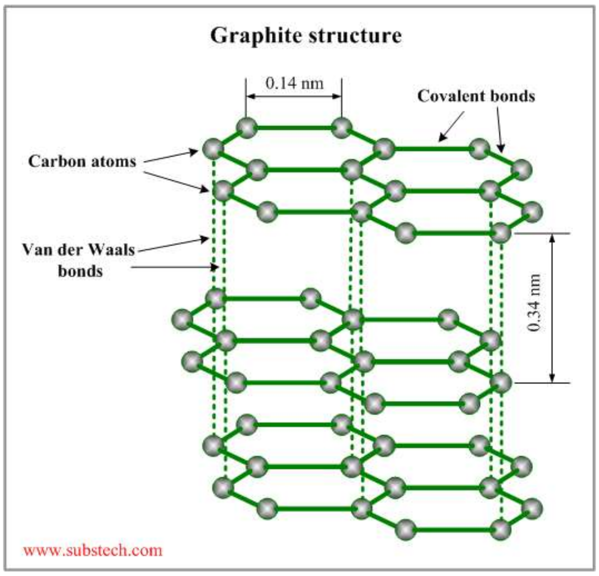
Electricity plays a key role in human development and well-being, making humanity completely dependent on this energy nowadays. Electrochemistry is the branch of chemistry that studies the transformation between chemical and electrical energy. These reactions are so called redox and are characterized by electron transfer between substances, producing a change in their oxidation states. They can be classified into two types: electrochemical, which are based on the ability to produce electrical energy through spontaneous chemical reactions, and electrolytic, which produce chemical changes through the use of electricity.

The concept of raw material refers to any good that aims to transform during a production process until it becomes an element of consumption. Many of the material goods require a modification or transformation before it can be used by users. For instance, the last generation of lighting is based on Light Emitting Diodes (LEDs) used in one of the experiences of this toolkit. These devices are a special type of semiconductor, whose main characteristic is to convert the low-voltage electric current through its chip into light. Each chemical compound of the semiconductor material used in the manufacture of a LED allows the emission of a light of a specific colour, corresponding to a certain wavelength of the electromagnetic spectrum. They contain some critical raw materials (CRMs) such as indium and gallium, that are raw materials economically and strategically important for the European economy, but have a high-risk associated with their supply. These CRMs are used as a semiconductors and allows us to obtain the blue (Indium) and red (Gallium) colours in the LEDs.

Water electrolysis technologies are currently used for hydrogen production. Although it is abundant on earth as an element, hydrogen is almost always found as part of another compound, such as water (H_2O) or methane (CH_4), and must be separated into pure hydrogen (H_2). Hydrogen production is an important field of study nowadays as this element can be used in fuel cells to generate power using a chemical reaction rather than combustion, producing only water and heat as byproducts. It can be used in cars, in houses, for portable power, and in many other applications. Hydrogen can be produced from diverse resources such as fossil fuels, biomass, and water electrolysis with electricity. Among various technologies for producing hydrogen, water electrolysis using electricity from renewable power sources shows great promise. In this toolkit students will produce water electrolysis themselves.

If the electricity for electrolysis come from renewable sources, the hydrogen produced will not have indirect emissions associated. Making green hydrogen a good solution for irregular supply of renewable energy, as it can act as an energy storage vector.

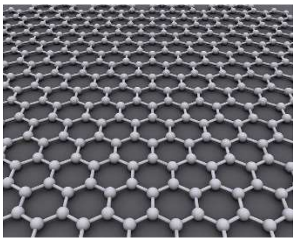
The electrical conductivity of a substance is a measure of the ease with which the valence electrons move throughout its structure. Metallic bonding produces the greatest conductivity, as it involves a lattice of positively charged nuclei, with electrons free to move throughout the lattice (Science Daily, 2010). When an electrical charge is applied to the metal, the electrons are able to easily move through it and therefore it can be said to be a good conductor. Substances bound by covalent bonding, on the other hand, are usually poor conductors (insulators) as the electrons are tightly held within the covalent bonds. There are some exceptions. For example, the covalent molecular substance graphite. Graphite, which can be found naturally, is the most stable form of carbon under standard conditions. Graphite is a pure carbon substance, where three of its valence electrons are covalently bonded to three other carbon atoms, forming a layered structure. However, the fourth valence electron is left un-bonded, and thus is able to move freely. These valence electrons allow the flow of electricity through the substance in certain directions when an electrical current is applied to graphite.



Teachers' Card

The "lead" in pencil is, contrary to its name, predominately made up of a combination of graphite and clay, with wax and other additives in small quantities. Clay, unlike graphite, is an insulator: that is, it does not conduct electricity well, due to the covalent bonds holding valence electrons tightly in place. The shade of pencil is dependent on percentage of each component. Pencils range from 9H, with 41 % graphite and 53 % clay, to 9B, with 93 % graphite and 1 % clay (Everything2 Media, 2012)

Graphite is a critical raw material for the EU economy because being a good conductor of heat and electricity, it has many uses in electronic products such as electrodes, batteries, and solar panels. Graphene is extracted from graphite and consists of a single layer of atoms arranged in a two-dimensional structure. It conducts electricity better than copper, is 200 times stronger than steel but six times lighter, is almost perfectly transparent, is impermeable to gases, and chemical components can be added to its surface to alter its properties. All these favourable characteristics make this material the focus of many material science projects.



Learning Outcomes

By the end of the lesson the students will be able to know:

- Water electrolysis principle and Galvanic cells principles.
- Different ways of generating energy.
- Ohm's law application and Multi-meter utilization.
- Conductivity of some materials such as graphite.

Key Competence European Framework

Literacy competence
S1. Ability to understand and interpret concepts, feelings, facts or opinions in oral and written form.
S2. Ability to express concepts, feelings, facts or opinion in written and oral form.
Multilingual competence
S1. Ability to understand and interpret concepts, feelings, facts or opinions in oral and written form.
S2. Ability to express concepts, feelings, facts or opinion in oral and written form.
S5. Knowledge of vocabulary, grammar and language.
S7. Ability to use technical language accordingly to the field of work.

EIT RawMaterials is supported by the EIT, a body of the European Union

Teachers' Card

Mathematical competence and competence in science, technology and engineering
S2. Understanding of mathematical term and concept and know how to apply it.
S3. Ability to model mathematically a situation from the real world and to transfer mathematical expertise to non mathematical contexts.
S5. Capacity for quantitative thinking.
S6. Ability to extract qualitative information from quantitative data
S8. Ability to design experimental and observational studies and analyse data resulting from them.
Digital competence
S4. Ability to use and handle technological tools and machines
Personal, social and learning to learn competence
S3. Ability to gain process and assimilate new knowledge, skills and qualification required for career goals.
Citizen competence
S3. Ability to work effectively and collaborate with other team members
Cultural awareness and expression competence
S3. Ability to plan and manage tasks

United Nations' Sustainable Development Goals

The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice. *Goals linked to this activity:*

	1 NO POVERTY 2 ZERO HUNGER Enable access to basic services		10 REDUCED INEQUALITIES Equal access to global expertise
	3 GOOD HEALTH AND WELL-BEING Safe medical devices		11 SUSTAINABLE CITIES AND COMMUNITIES Sustainable urbanization
✓	4 QUALITY EDUCATION Access to education		12 RESPONSIBLE CONSUMPTION AND PRODUCTION Responsible consumption and production
	5 GENDER EQUALITY Less hardship, more opportunities		13 CLIMATE ACTION Strengthen resilience, reduce disaster impact

EIT RawMaterials is supported by the EIT, a body of the European Union

	6 CLEAN WATER AND SANITATION — Safe and affordable water		14 LIFE BELOW WATER — Reduce marine pollution
✓	7 AFFORDABLE AND CLEAN ENERGY — Energy – the golden thread		15 LIFE ON LAND — Sustainable use of terrestrial ecosystems
	8 DECENT WORK AND ECONOMIC GROWTH — Safety of workers and economic growth		16 PEACE, JUSTICE AND STRONG INSTITUTIONS — Promote peaceful and inclusive societies
	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Resilient infrastructure and sustainable industrialization		17 PARTNERSHIPS FOR THE GOALS — Better access to technology and innovation

Contents – Theoretical principles

A REDOX reaction can be defined as a chemical reaction in which electrons are transferred between chemical species, producing a change in their oxidation state.

The specie that losses electrons is oxidized and it is called reductant. The specie that gains electrons is reduced and it is called oxidant.

The oxidation and reduction semi-reactions always occur at the same time and, because of their complementary nature of both processes together, are referred to as redox reactions.

Oxidation: e- loss → ↑oxidation number → reducing agent

Reduction: e- gain → ↓oxidation number → oxidizing agent

Electrochemical cells can be divided in:

- **Electrolytic cell:** This device achieves a non-spontaneous redox reaction by providing electricity. In particular, electrolysis of water would be the decomposition of water into oxygen and hydrogen gas due to the passage of a current, which ideally requires a potential difference of 1.23 volts. If common salt was added, the gases that will be formed would be chlorine and hydrogen instead, as shown in the following reaction (the ideal ratio for electrolysis is 10 % salt and 90 % of water):

$$2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH$$

- **Galvanic or voltaic cell:** Batteries are chemical cells that convert chemical energy into electricity spontaneously. The chemicals inside it cause a reduction-oxidation reaction, which produces energy that could, for example, light a LED. In some cases, it is necessary to provide protons through the presence of an acidic substance

As regards the electrical conductivity of graphite pencils, these are the percentages of carbon in pencils and the shades of lead pencils

Hardness	9H	8H	7H	6H	5H	4H	3H	2H	H	F	HB	B	2B	3B	4B	5B	6B	7B	8B	9B
Carbon (%)	41	44	47	50	52	55	58	60	63	66	68	71	74	76	79	82	84	87	90	93
Clay (%)	53	50	47	45	42	39	36	34	31	28	26	23	20	18	15	12	10	7	5	2

Lab Procedure/Activity

The laboratory activities consist in three different experiences, grouped into two modules:

1) (A) Hydrogen gas production by the electrolysis of water, using a battery and a saline solution
   (B) Test the conductivity of graphite, using different hardness pencils, a battery and a multimeter.
2) Make a battery using potatoes, zinc and copper to produce electricity to turn on a LED:

This experiment aims to emulate a battery replacing it with potatoes that contain phosphoric acid, which act as the battery acid. It reacts with the zinc and copper metals in the nail and coin to start the electricity flowing. On one hand, the acid in the potato consumes the zinc metal that coats the galvanized nail, releasing negatively-charged electrons around it and thus becoming the negative end of the battery. On the other hand, the acid in the potato reacts with the copper metal that coats the coin, absorbing electrons from the copper. Electrons have a negative charge so, as they are removed from the copper, the coin becomes the positive end of the battery.

The reactions between the acid in the potato and the two metals create an imbalance in electrical charge: there are more negatively-charged electrons at the zinc end than at the copper end. The wires let these electrons flow quickly from the zinc to the copper to correct this imbalance, which creates an electrical current. Connecting several potatoes in series using pieces of wire adds the power of each potato to create a stronger battery.

Module 1 – Electrolysis of water and graphite conductivity

Module 2 – Potato galvanic cell construction

EIT RawMaterials is supported by the EIT, a body of the European Union

Learning Pathway

Step 1 (10 minutes) – Teachers give a short reminder about redox reactions principles.

Step 2 (20 minutes) – Students read the 'Introduction' of Students' Card 1 and complete the water electrolysis experiment following the 'Lab Procedure' of Students' Card 1 (the container with the pencils can be prepared beforehand).

Step 3 (15 minutes) – Students complete the pencils conductivity experiment following the 'Lab Procedure' of Students' Card 1.

Step 4 (20 minutes) – Students read the 'Introduction' of Students' Card 2 and complete the potato battery experiment following the 'Lab Procedure' of their Students' Card 1.

Step 5 (20 minutes) – Students complete the 'Questions' of Students' Card 1 and 2 by their own.

Step 6 (15 minutes) – Pooling the results and discussion of the answers to the questions.

Evaluation

The activity could be evaluated with a lab report or by qualifying students' answer to 'Questions'.

The second option can be done by collecting the students' answers before discussing them (that means doing step 6 when the teacher has already collected the answers instead of right after the experiment), or by asking students to give their answer paper to a classmate and discussing the correct answers all together. In this way every student will be checking someone else's answers. The teacher has to collect the papers after that so he can note down the marks.

Description of Student's Cards

Student's Card 1 - Electrolysis of water and graphite conductivity

Student's Card 2 - Potato galvanic cell construction

EIT RawMaterials is supported by the EIT, a body of the European Union

Sources

- DramaticIron, 2018, *Potato Battery: Understanding Chemical and Electrical Energy*, Instructables circuits, accessed 13 May 2021, https://www.instructables.com/Potato-Battery-Understanding-Chemical-and-Electric/
- Deziel, C., 2018, *How to make a potato battery*, Sciencing, accessed 10 May 2021, https://sciencing.com/make-potato-battery-6537882.html
- European Comission, *Critical raw materials*, accessed 20 April 2021, https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en
- AlexZander, 2012, *Pencil lead*, Everything2 Media, accessed 29 April 2021, http://everything2.com/title/Pencil+lead
- Kopeliovich, D., 2013, *Graphite*, Substances and Technologies, accessed 27 April, http://www.substech.com/dokuwiki/doku.php?id=graphite
- Science Daily, 2010, *Electrical conduction*, accessed 24 May 2021, http://www.sciencedaily.com/articles/e/electrical_conduction.html
- Sousa, M., & Buchanan, J., 2000, *Observational Models of Graphite Pencil Materials*. Computer Graphics Forum, 19, 27-49.
- WikiHow, 2021, *How to create a potato battery*, accessed 12 May 2021, https://www.wikihow.com/Create-a-Potato-Battery

Acknowledgement

This document has been prepared by: Helena Bueno, Teófilo Jiménez and Elena Pérez, supervised by Miguel López from Colegio Institución La Salle, Madrid.

In collaboration with: Isabel Ámez, David Bolonio, Blanca Castells, Miguel Izquierdo, Ljiljana Medic, Christian Peña, Andrea Ruiz and María Zúñiga from School of Mining and Energy Engineering, Universidad Politécnica de Madrid.

EIT RawMaterials is supported by the EIT, a body of the European Union