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Elegant electrolysis – the microscale way

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Enhance your students' knowledge of electrolysis using quick, safe, and easy microscale chemistry techniques.

Electrolysis is a process that is fundamental for extracting relatively reactive metals, such as aluminium, lithium, and magnesium. Chlorine and sodium hydroxide, used in fighting viruses and bacteria, are made by the chloralkali process, which involves the electrolysis of aqueous sodium chloride.

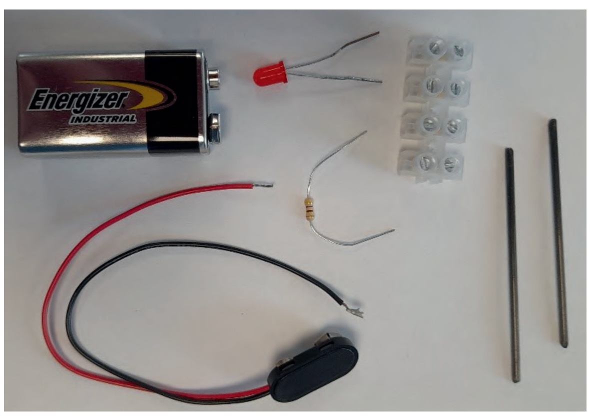
When teaching conductivity and electrolysis, microscale techniques are very rewarding due to the speed at which students can work, and they allow the teacher to challenge the misconceptions in understanding that arise.

Activity 1: Construction of a microscale conductivity meter

The conductivity meter is a simple device that allows students to investigate the conductivity of a range of solid materials (such as copper and glass) and compounds in different states (such as solid sodium chloride and sodium chloride solution). This device, which is a variation of the CLEAPSS conductivity indicator GL16609(1), was originally developed by Matthias Ducci at the Pädagogische Hochschule Karlsruhe. A class set of these devices can be made by the teacher or technician, although students can also make these as part of the classroom activity or in science clubs. They can made in under 30 minutes.

Materials

- 2 mm carbon fibre rods (these are available from online kite shops, see notes below)
- Section of electrical terminal block
- Two-terminal-wide battery clip with connecting wires
- Resistor (390–500 Ω, 0.25 W)
- 20 mA light-emitting diode (LED)
- 9 V PP3 battery
- Small screwdriver
- Needle-nose pliers
- Wire cutters
- Hacksaw or knife
- Tic Tac box (49 g)
- Double-sided adhesive tape
- Nail, pliers, and Bunsen burner



Conductivity meter components
Image courtesy of Adrian Allan

Procedure

1. Cut 2 cm x 5 cm lengths of carbon fibre rods with sharp wire cutters inside a box, if possible, to prevent them flying across the room.
2. Clip the wires of the resistor to approximately half their length and loop the ends over with a pair of needle-nose pliers. Inclusion of the resistor in the circuit limits the current flowing through the LED.
3. Use a hacksaw or a hot knife to cut a section containing four connectors from a terminal block.
4. Insert the ends of the black wire of the battery clip into the outermost connection on the right side of the terminal block.

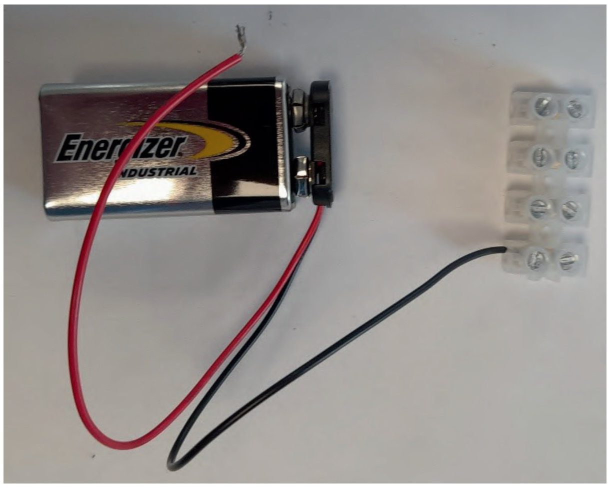


Image courtesy of Adrian Allan

5. Insert one end of the resistor into the same connection on the same side of the terminal block as the black wire, and the other end into the connection next to it on the same side. Tighten the screws to hold the wire and resistor firmly in place.

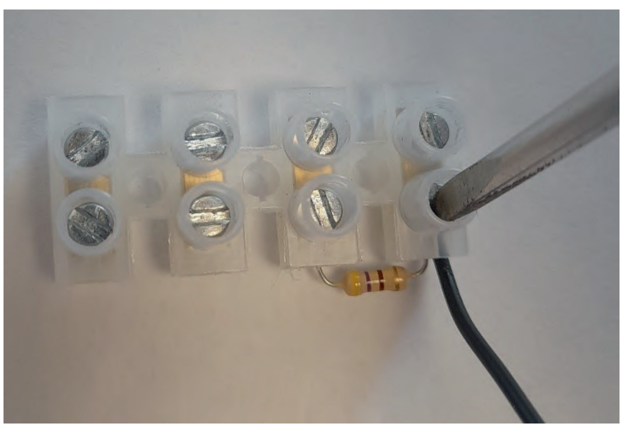


Image courtesy of Adrian Allan

6. Insert the ends of the red wire of the battery clip into the outermost connection on the left side of the terminal block.
7. Insert the positive arm of the LED (the long one) so it fits through the same connection as the end of the red wire. Insert the other arm of the LED into the connection next to it on the same side. Tighten the screws to hold the wire and LED firmly in place.

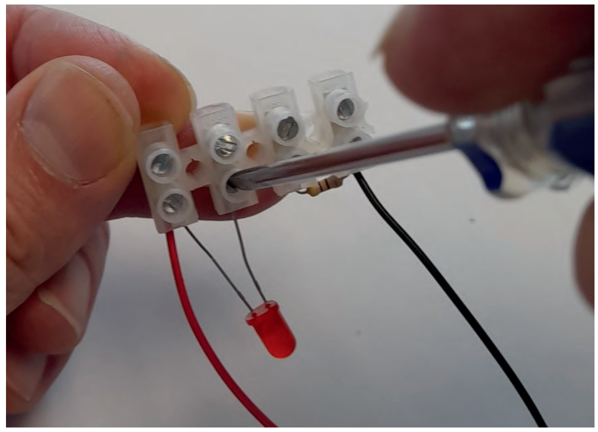
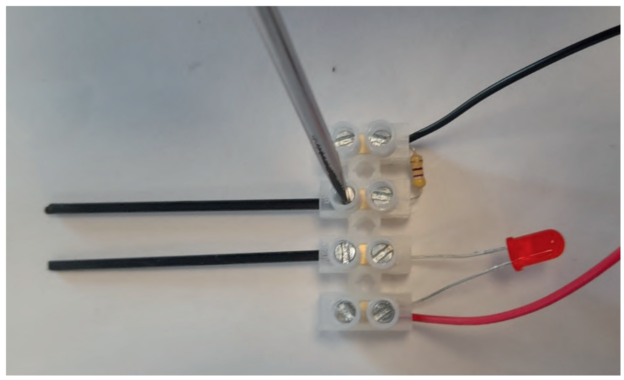


Image courtesy of Adrian Allan

8. Take the two lengths of carbon fibre rod and insert them into the middle two holes in the other side of the terminal block. You will have to open the hole fully and push a bit to manage this. Tighten the screws.



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9. Connect the battery onto the clip. When you have finished, it should look the apparatus shown below. The meter can be used as it is and tested at this stage with a drop of salt solution.

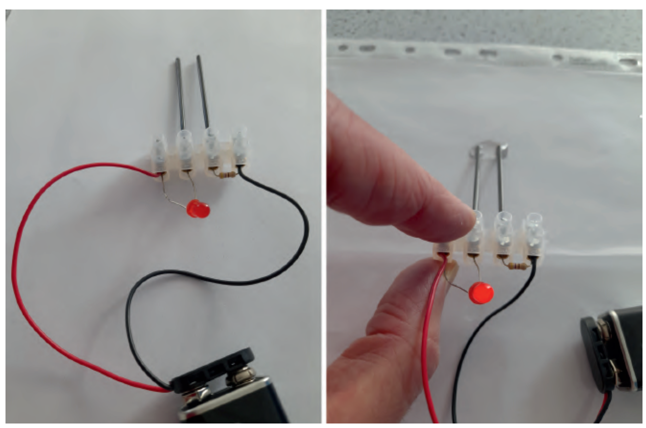


Image courtesy of Adrian Allan

10. To make a protective case for the conductivity meter, use a hot nail make two holes in the end of a Tic Tac box that are the same distance apart as the two electrodes, about 2 mm from the edge.

Image courtesy of Adrian Allan

11. Attach double-sided adhesive tape to the base of the terminal block. Push the electrodes inside the Tic Tac box and through the holes at the end. The tape will fix the terminal base to the box.

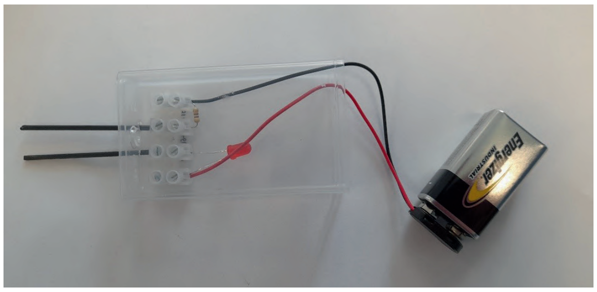
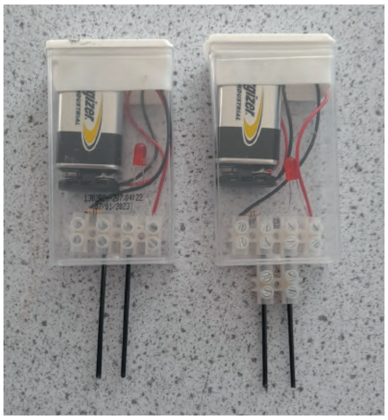


Image courtesy of Adrian Allan

12. Attach tape to the base of the battery, fix to the inside of the lid of the box, and push the lid with the battery into the box. An alternative to using tape to hold the carbon electrodes in place is to use a section containing two connectors cut from a terminal block.



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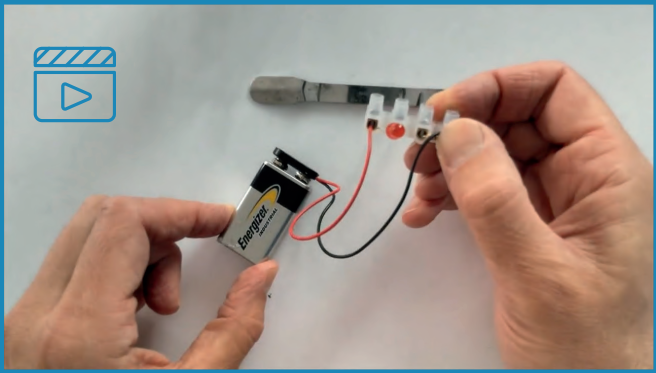
The full assembly process can observed be in this video:



Additional notes and tips

If you put black card/paper behind the LED, you can see the light better.

The carbon fibre rods (2 mm in diameter) are easily (and often less expensive than graphite rods) available from online suppliers. The carbon fibre rods are used for frames in kites and model aircraft, as they are extremely strong and 'snippers' are required to cut them.

Metals and alloys, such as copper, iron (paper clips), zinc wire, aluminium wire, and nichrome wire, can also be used as electrodes; however, the products are often different. For instance, copper sulfate solution with copper electrodes results in copper at the positive electrode dissolving, and copper being deposited at the negative electrode. If carbon electrodes are used, carbon dioxide is produced at the positive electrode. At the negative electrode, copper is deposited and hydrogen gas begins to appear, as the concentration of copper ions decreases.

Activity 2: Conductivity and ions in solution

The conductivity of solutions allows discussions with students on topics such as the presence of ions in solution, the production of useful chemicals, and electroplating. This activity teaches students that, for solutions to conduct, ions must be present. It illustrates important concepts relating to atomic structure, ion formation, and ionic and covalent bonding.

Materials

- Dropper bottle of distilled water
- Dropper bottle of tap water
- Sodium chloride crystals
- White granulated sugar
- Brown sugar
- Conductivity meter
- Wooden splint
- Conductivity and ions in solution worksheet

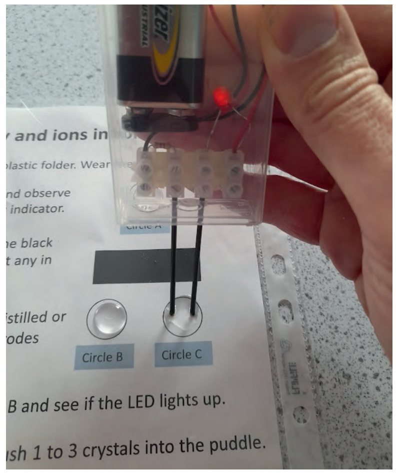
Procedure

1. Print out a copy of the worksheet and place it in a clear plastic wallet.
2. Place a few grains of salt near to where the puddle will be placed.
3. Make a puddle of tap water in the box provided.
4. Test the conductivity of tap water by putting the electrodes in the puddle. The LED should light up.
5. Fill another circle with distilled water and test the conductivity. Compare the conductivity of tap water and distilled water using the conductivity meter.
6. Push a few crystals of salt to the edge of a puddle of distilled water, so they just enter the liquid.
7. Hold the electrodes steady in the puddles and observe over the next minute.
8. Place a few crystals of white sugar and soft brown sugar in separate puddles and compare the conductivity.

Discussion

Discuss the following questions with your students:

- How does the conductivity of saltwater compare with distilled water?
- How does the conductivity of tap water compare with distilled water?
- How does the conductivity of white sugar solution compare with salt solution?
- How does the conductivity of white sugar solution compare with brown sugar solution?
- When a solution conducts electricity, what does this indicate the presence of?
- Which ions could be present in the solutions, and what would their charges be?
- Why would it be dangerous to swim in the sea during a thunderstorm or have an electrical device near a bath?



Conductivity meter in a drop of distilled water with crystals of sodium chloride added
Image courtesy of Adrian Allan

Explanation

When sodium chloride crystals dissolve in the water drop, the ions are free to move, diffusing through the liquid. As the ions encounter the electrodes, the circuit is complete, as shown by the LED lighting up. Therefore, the conductivity meter is detecting the presence of ions in solution. Tap water will contain a small amount of ions that will cause an LED to light up, unlike distilled water. White sugar is composed of sucrose, a covalent molecular compound, and will not produce ions when dissolved in water, giving little signal on the LED. Soft brown sugar (molasses) contains impurities that will form ions in water, giving a brighter signal on the LED. In some cases, brown sugar may show no signal, which may suggest that the sugar has a food dye added.

Although this piece of apparatus is commonly known as a conductivity meter, it can also be described as an ion detector. Any solution that contains ions will conduct electricity; therefore, it is not a good idea to swim in the sea during a thunderstorm or use a hairdryer in the bath!

Extension activities

Electrolysis experiments using the conductivity meter

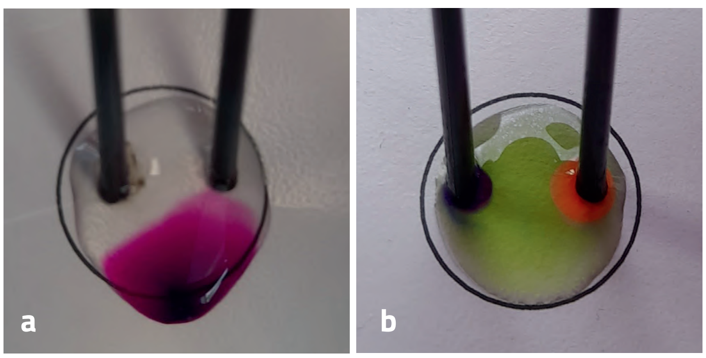
Place some potassium manganate(VII) crystals at the edge of a puddle of distilled water.

Caution:

Potassium manganate is a harmful oxidizer.

As the purple colour diffuses, insert the electrodes into the drop and observe. The purple colour moves towards the positive electrode due to the negative charge of manganate(VII) ions (MnO_4^-). This can also be done with copper sulfate crystals in a drop of 2 M ammonia; copper metal appears at the positive electrode. Other salts can also be tried.

Alternatively, add universal indicator to a puddle of water and insert the electrodes. Keep them still for a minute and remove carefully. There will be an orangey red acidic area around the positive electrode and a blueish–purple alkaline area around the negative electrode. This is caused by electrolysis on the electrode surface.

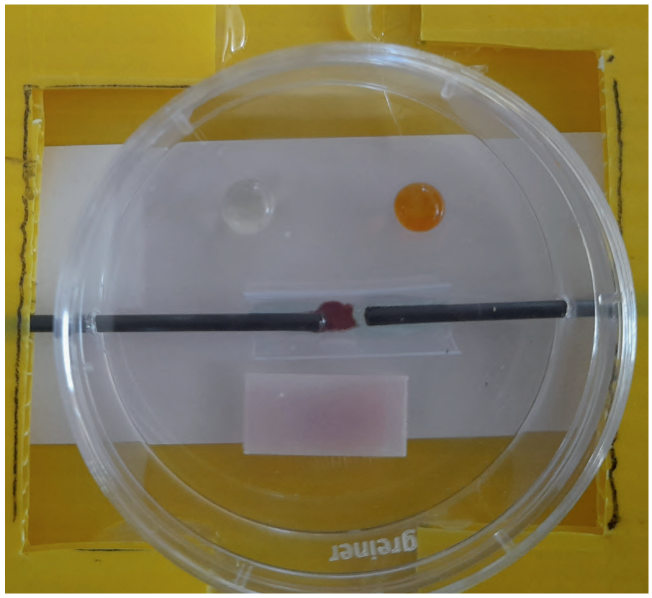


a) Conductivity meter in a drop of tap water with potassium manganate(VII). Note how the purple colour is migrating towards the positive electrode. b) Conductivity meter in a drop of tap water with universal indicator

Image courtesy of Adrian Allan

Microscale electrolysis of copper(II) chloride

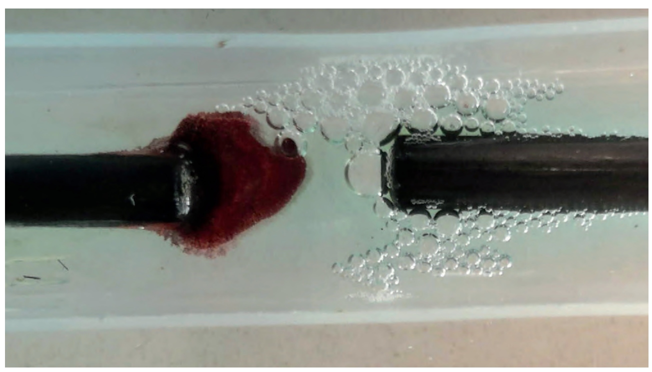
Safety becomes an issue when copper chloride salts are electrolyzed to chlorine. In the UK, the electrolysis of copper(II) chloride was promoted by exam specification because the solution conveniently produces copper and chlorine at the electrodes. The toxic nature of chlorine sent students to hospital with breathing difficulties. The use of a Petri dish in the apparatus can limit the volume of chlorine produced to 6 cm^3 of gas, which is enough to be identified by bleaching and oxidising reactions. Full instructions for construction of the microscale electrolysis apparatus are given in the supplemental material.



Microelectrolysis of copper chloride solution

Image courtesy of Adrian Allan

If copper(II) chloride is electrolyzed, brown copper is observed to form at the negative electrode, and chlorine can be seen as bubbles at the positive electrode, and faintly smelled.



Microelectrolysis of copper chloride solution, close-up

Image courtesy of Adrian Allan

Electrolysis of copper(II) chloride

Notes

Electrolysis can be a tricky concept that is not as straightforward as textbooks would have you believe, and simplification can often mask what is going on. These are points to consider when performing these activities with students:

1. It is not only the ionic salt that can take part in redox reactions at the electrodes; the solvent may react too.
2. Unlike inert platinum electrodes, the carbon electrodes themselves can enter into the reactions, particularly at the positive electrode.
3. There are often competing reactions occurring so that a mixture of products form at each electrode.
4. The products often depend on the concentration of the salt in the solvent.

References

[1] Andre C (2016) Chemie? Aber sicher! Experimente kennen und können! Akademie für Lehrerfortbildung und Personalführung (ALP), Dillingen. https://www.deutsche-digitale-bibliothek.de/item/IWYNTP6YBCLOMKKRJBVUFEALZ2DRJMQO

[2] Worley B, Paterson D (2021) Understanding chemistry through microscale practical work p 70. Association for Science Education. ISBN: 9780863574788

Resources

- Follow a video make-it guide for constructing the microscale conductivity meter.
- Demonstrations of the experiments in this article can be found in this Science on Stage webinar on microscale chemistry.
- Watch a demonstration of the microscale electrolysis of copper chloride experiment.
- Read an introduction to microscale chemistry in the classroom: Worley B (2021) Little wonder: microscale chemistry in the classroom. *Science in School* **53**.
- Teach about pH chemistry using microscale methods: Worley B, Allan A (2021) Little wonder: pH experiments the microscale way. *Science in School* **54.**
- Teach the chemistry of precipitation using microscale chemistry methods: Worley B, Allan A (2022) Pleasing precipitation performances – the microscale way. *Science in School* **54**.
- Try a classroom activity to extract essential oils from fragrant plants: Allan A, Worley B, Owen M (2018) Perfumes with a pop: aroma chemistry with essential oils. *Science in School* **44**: 40–46.
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- Learn how to make indicators from butterfly tea: Prolongo M, Pinto G (2021) Tea-time chemistry. *Science in School* **52**.

AUTHOR BIOGRAPHY

Dr Adrian Allan is a teacher of chemistry at Dornoch Academy, UK. He was selected to represent the UK at the Science on Stage conferences in 2017 and 2019. He has presented Science on Stage webinars and workshops around Europe on microscale chemistry and using magic to teach science.

Bob Worley, FRSC, is the (semiretired) chemistry advisor for CLEAPSS in the UK. He taught chemistry for 20 years, and in 1991, he joined CLEAPSS, which provides safety and advisory support for classroom experiments. In carrying out these duties, he gained an interest in miniaturizing experiments to improve safety and convenience. He was awarded the 2021 Excellence in Secondary and Further Education Prize for significant and sustained contributions to the development and promotion of safe practical resources for teachers worldwide.