ROYAL SOCIETY OF CHEMISTRY

Take charge

Global battery experiment

Investigation 2

Teaching notes

rsc.li/takecharge

Overview of the investigations

In the **Take charge: global battery experiment** learners can explore batteries and the important role they play in a sustainable future by making their own.

There are two investigations in this global experiment. Both experiments give learners a chance to build a coin battery and practise scientific enquiry skills.

Investigation 1

Make your own coin battery and use it to light up an LED. How many cells does it take?

- Uses only everyday materials.
- Can be done anywhere.
- Share your results and see how they compare with others around the world.
- Target age range: 9–14.

Investigation 2

Compare batteries made from different materials. Which battery performs best?

- Still simple to set up and do, but you will use a voltmeter and test different electrolytes.
- Should be done in a science laboratory.
- Generate and compare data with your class and globally.
- Target age range: 11–14.

These teaching notes will support you to join in with investigation 2. In addition, at rsc.li/takecharge there is:

- An introduction video to help link this experiment to the topic of sustainability and what scientists are currently working on to develop better batteries. You can watch this with learners before or after running the investigation.
- A teacher video showing how to carry out the experiment.
- PowerPoint slides including some background and the instructions for learners (also available as pdf).
- A results worksheet for learners to record their results. Note to bulk upload your results use the results table template available on the website.
- A battery power worksheet, to learn more about battery research and development from the past to the present day.

Contents

Introduction

To end climate change, we need to stop using fossil fuels in our homes and cars and switch to zero carbon and renewable power such as solar and wind.

We are developing more and more renewable energy resources but many of them only generate electricity in specific circumstances such as when it's sunny or windy. We need to be able to store the electricity generated at those times for use whenever and wherever it is needed.

That's where batteries come in. Batteries allow us to store energy to use whenever we need it. Batteries are a big part of the solution we need to achieve net zero carbon dioxide emissions and become a sustainable society.

Batteries are composed of different layers, each made of a different material. As we need so many batteries to meet the energy demand, the materials we use for these layers are very important. Scientists are trying to create better batteries that are efficient and made from abundant materials.

In this task, learners will create batteries made of different materials to record which has the best performance. This will be measured by the potential difference (voltage).

Learning objectives

- Understand that batteries are made up of cells, comprised of layers of different materials.
- Understand that batteries store energy as chemical energy.

Enquiry skills

This investigation covers many different scientific enquiry skills. You may want to choose just one or two to focus on.

Scientific attitudes:

- Pay attention to objectivity as well as accuracy, precision, repeatability and reproducibility.

Experimental skills and investigations:

- Make and record measurements using a range of methods. Evaluate the reliability of the methods and suggest possible improvements.

Analysis and evaluation:

- Present observations and data using appropriate methods including graphs.
- Interpret observations and data to draw conclusions.
- Identify further questions arising from results.

Background science

Most of the science behind how a coin battery works is beyond what learners in this age group are expected to understand. However, in simple terms, batteries use chemical reactions to drive a current, when connected to a complete circuit. The current is made up of a complete loop of electrons which are driven from the negative electrode towards the positive one.

Each cell within a battery is made up of two electrodes made of different materials, usually dissimilar metals. One metal will form the positive electrode and the other the negative electrode. Between these electrodes is an electrolyte, a liquid (or gel) that allows charged particles to move through it freely. A chemical reaction takes place at each electrode providing the push of energy that keeps the charged particles in motion.

In this experiment the learners (aged 11–14) will hopefully take away the following:

- A cell uses chemical reactions to make a current flow around a complete circuit.
- A battery is formed from one or more cells joined together.
- Cells are made up of different layers comprised of different materials (we use a coin, aluminium foil and cardboard soaked with an electrolyte).
- Changing the number of cells will affect the performance of the battery.
- Changing the electrolyte will affect the performance of the battery.

Engaged learners may ask questions relating to the experiment and this should be encouraged. In the FAQ section below we have provided some learner-friendly answers to questions that you may be asked.

If you would like to know more about the underlying chemistry behind the experiment, please read the ‘understanding the chemistry’ section at the end of these notes.

Prior learning

Using all the materials provided you can be confident that learners aged 11–14 will be able to access this investigation with minimal prior knowledge.

Some learners may have previously constructed or seen a simple series electrical circuit, including cells and wires. This will have given them the opportunity to observe patterns, for example that bulbs get brighter if more cells are added, that metals tend to be conductors of electricity, and that some materials can be used to connect a circuit. Before beginning this experiment it’s useful if learners:

- Can identify common appliances that run on electricity.
- Understand batteries allow us to store energy for when it is needed.
- Associate the potential difference (voltage) in an experiment and the brightness of a lamp or the volume of a buzzer.
- Know that energy can be transferred from one form to another.

Useful vocabulary

Cell – a device that stores energy and uses chemical reactions to make a current flow in a complete circuit.

Battery – made up of one or more cells joined together.

Circuit – contains a power supply (such as a battery) and a component (such as an LED) connected by wires. A circuit needs to be complete (closed) to work.

Current – the flow of charged particles around a circuit.

Electrode – a battery has two electrodes made of different materials, one positive and one negative.

Electrolyte – a liquid that will conduct an electric current.

Teachers may wish to hide the meanings/examples on the PowerPoint slide and discuss the learners' ideas first.

Starter activities

The introduction video (at rsc.li/takecharge) helps link this experiment to the topic of sustainability and the work scientists are currently doing to develop better batteries. Learners can watch this before the investigation.

What is a battery? (slide 4 in the learner PowerPoint) show images of different types of batteries. You could use these to start a conversation about batteries – what they are used for and different types. Or use images 3, 4 or 5 and ask learners to find out more about these topics prior to the lesson.

- Image 1 shows AA batteries. This type of battery is familiar to most learners. They are used in toys, torches and many other everyday items. Rechargeable versions of these batteries are available.
- Image 2 shows what some people call a single-cell battery. These miniature batteries power items such as watches or hearing aids. (They are dangerous for small children as they can cause internal burns if swallowed.)
- Image 3 shows the voltaic pile, the first simple battery built by Alessandro Volta in 1799. The coin battery you build in this experiment is a version of Volta's battery.
- Image 4 shows a battery in a mobile phone. Mobile phone batteries are rechargeable, compact and lightweight. They are lithium ion batteries, a different type of battery to those in image 1 and 2.
- Image 5 shows a battery at a wind farm in the Netherlands – 88 car batteries are connected to form a mega-battery. When the wind blows strongly the energy generated can be too much for the electricity grid to handle. This battery stores the extra energy to deliver to the grid when there is less wind.

Equipment list

Each group of learners should have:

- 10 x coins (the same)
- aluminium foil
- cardboard
- voltmeter (or multimeter)
- 2 x Petri dishes (or similar)
- tweezers
- pencil
- sticky tape

Each group to test one electrolyte from the following list:

- vinegar, 5%; equivalent to ethanoic (acetic) acid solution, 0.8 mol dm^{-3}
- sulfuric acid solution, 0.4 mol dm^{-3}
- sodium chloride solution, 1.0 mol dm^{-3} (1 teaspoon salt in 100 ml water)
- sodium hydroxide solution, 0.1 mol dm^{-3}
- deionised water (distilled water can also be used)

Safety

Wear eye protection.

Although the solutions used in this experiment are not classed as hazardous we recommend using tweezers when immersing and removing the cardboard discs from the solutions and to reduce handling.

Read our standard health & safety guidance and carry out a risk assessment before any practical work.

Equipment tips

Coins: it doesn't matter what type of coin is used – washers can also be used. Larger, slimmer coins are the easiest to work with.

Aluminium foil: standard household aluminium foil. Thicker foil (eg extra-strong) is easier to handle.

Cardboard: the images and video give a good guide to the ideal thickness for the cardboard. If it is too thick it will be hard to cut out and require longer soaking, and if it is too thin it may disintegrate.

Sticky tape may help to secure the stack as you add more cells.

Method

Explain to your class that you are all going to be making batteries and testing their performance by changing what they are made of.

Once you have introduced the practical, you can demonstrate each step as you go along and allow time for learners to copy after each one. This allows opportunities for you to ask learners to make predictions about what might happen and to discuss. Some example question prompts are provided in italics below.

To set up

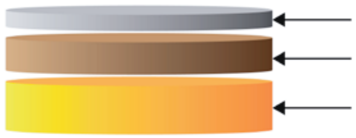
1. Use the coin to draw cardboard discs of the same size, then cut them out.
2. Fold a square of aluminium foil four times, draw around the coin, cut out and separate the layers.

> **TIP**
> Separate the foil carefully so the discs don't tear and remain full circles.
>
> (Depending on time available you could prepare steps 1 and 2 ahead of the lesson – it takes learners around 10 minutes to complete these steps themselves.)

3. Soak the carboard discs in the electrolyte you are testing for about one minute.
4. Remove the discs from the vinegar and place them in the second dish for a few minutes to remove any excess liquid before assembling the battery.

Make the first cell

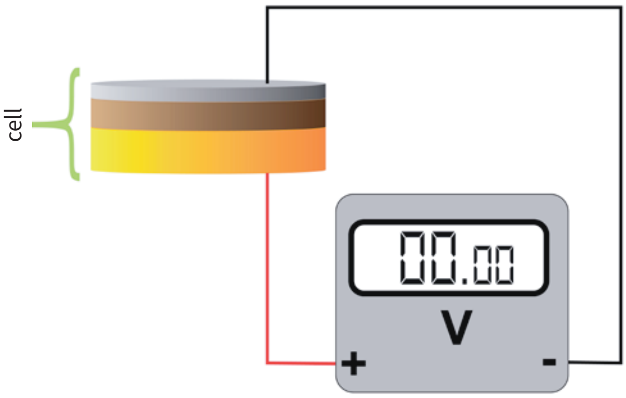
1 **Stack a coin, a pre-soaked cardboard disc and a disc of aluminium foil to make a cell.**



2. **Connect the cell to a voltmeter.**

   Ask learners to predict what will happen to the voltmeter when it is connected to the cell. Ask them why they think this and allow for a class discussion.

   > TIP
   > If you are using multimeters make sure learners have selected the correct setting to measure volts.
   > Connect the positive terminal to the coin and the negative to aluminium foil.



   Ask learners to predict or to find out what happens if they put the wires the other way around.

3. **Record the potential difference.**

   Use the results table template or ask learners to create their own table to record their results.

   Explain that they are going to add another cell and ask learners to predict the impact this will have on the performance. Does a higher potential difference relate to a greater performance?

4. **Add another cell and record the potential difference again.**

   > TIP
   > Keep the stack of cells neat – don't let the foil move down the side or this could short circuit the battery.

   Ask learners if the results matched their prediction or not. Explain they will repeat this process and record their results until they have 10 cells. Ask if they can predict what will happen to the potential difference.

5. **Repeat the process adding up to a maximum of nine additional cells.**

   Ask learners to make predictions about how the results from the electrolyte they are testing will compare with others. Ask them which electrolyte they think will result in the largest potential difference and ask them for a reason. For some this will be a guess, some may predict that distilled water may be less but won't fully understand why.

6. **Compare results from different electrolytes.**

   Ask learners what sort of graph they should use to record their results. They may be familiar with discrete and continuous data and how this links to a bar chart or a line graph being produced. As both the dependent variable (potential difference, V) and the independent variable (number of cells) are examples of continuous data, a line graph can be produced for each of the different electrolytes.

7. **Enter your data on the website.**

   You can enter your data directly or upload the results table template to share your results and generate graphs to compare the performance of the electrolytes.

Expected results

One example set of results is given here as a guide. Check rsc.li/takecharge for the latest global results.

Number of cells	Potential difference (V)				
	Vinegar (5%)	Deionised water	Saline solution	Sodium hydroxide (0.1 M)	Sulfuric acid (0.4 M)
1	0.55	0.55	0.53	0.97	0.52
2	1.05	1.08	0.90	2.14	1.10
3	1.30	1.50	1.40	2.87	1.68
4	1.52	1.80	1.84	3.67	2.20
5	1.90	2.39	2.30	4.76	2.67
6	2.20	2.84	2.67	5.27	3.20
7	2.40	3.24	2.90	5.97	3.73
8	2.60	3.76	3.25	6.72	4.24
9	2.85	4.01	3.86	7.83	4.78
10	3.20	4.40	4.12	8.66	5.39

The alkaline solution sodium hydroxide will perform best as an electrolyte. The vinegar will perform worse than the saline solution and deionised water. However, the stronger acid will perform better. (This is due to different reactions taking place at the negative electrode, see 'understanding the chemistry' below.) Learners at this level will take away the understanding that changing the electrolyte can affect the performance of a battery.

Other observations

Learners may also observe small holes in the aluminium foil after using the battery for some time, as the aluminium reacts with the electrolyte.

Ask learners if these holes are a problem and link it to sourcing materials to make batteries and the importance of battery recycling.

Extension activities

- Use your battery. You can try connecting an LED, buzzer or lamp to your battery to see it in action.
- What other electrolytes could you test? How do you predict they might perform based on the results from this investigation?
- Investigate the effect on performance if you change other materials in your battery.
  - Which metals could you test in place of the aluminium foil?
  - Do different types of coin produce different results?
  - What things should you consider when choosing the material to replace the aluminium foil or coin electrodes? (As long as the electrodes are made of different metals you can use almost any metal.)
- How do you predict the thickness of the cardboard would impact on the performance of your battery? Design an experiment to test batteries that uses different materials to absorb the electrolyte. (Cloth, paper and different thicknesses of cardboard could be tested.)
- How long will the battery last? Do different electrolytes produce batteries that last longer?

FAQs

As noted above, some of the questions learners may ask require a deeper understanding of chemistry to fully explain them. However, here are some 'learner-friendly' answers to frequently asked questions. For more FAQs, go to rsc.li/takecharge.

1. Why does the sodium hydroxide produce a larger potential difference than the other materials?
   Different solutions cause the chemical reactions to happen at different rates and can create a bigger 'push' of current around the circuit.
2. Why are there small holes in the aluminium foil after using the battery?
   The aluminium reacts with the electrolyte leading to the aluminium foil being used up.
3. Why do more cells lead to a greater potential difference?
   With more cells, the 'push' of current round the circuit is greater.
4. Why are the cardboard discs dipped in a solution (the electrolyte)?
   The particles in a solid cannot carry the flow of charge from one electrolyte to another.
5. Why does the battery run out?
   Batteries 'run out' when one of the chemicals taking part in the reactions has fully reacted and is no longer available.
6. How do rechargeable batteries work?
   A rechargeable battery works in the same way as a coin cell when being used. However, the chemicals inside are different. When they 'run out' they can be connected to a charger to reverse the chemical reactions and 'recharge' them.
7. Could we get a shock if we made a really high stack?
   If you make a voltaic pile with more than 10 cells it is possible to get a small electric shock from it. This is how Volta originally measured how powerful his batteries were by giving himself electric shocks.

Follow-up

Once you have completed your investigation, don't forget to share your results on the website (rsc.li/takecharge) and see how they compare with other schools around the world.

Use the information and activities in the battery power worksheet (available at rsc.li/takecharge) to find out more about batteries and how they will be important for supporting our energy needs in the future.

Explore how learners use electricity in their daily lives and the impact that has on the environment. What can they do to reduce their electricity usage and become more sustainable citizens? Use the website (rsc.li/takecharge) to find and share ideas and to make a commitment.

Understanding the chemistry

In this experiment the coin is just there to conduct electrons, it can be replaced by anything conductive, eg graphite.

The reactions taking place at each electrode for all electrolytes except for the sulfuric acid are:

- ***At the aluminium foil anode*** $Al + 3OH^- \rightarrow Al(OH)_3 + 3e^-$ (-2.31 V)
- ***At the coin cathode*** $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (+0.40 V)

These equations also explain why the deionised water with the cardboard produces good results.

The battery needs both reactions to work. The aluminium anode provides the electrons needed to drive a current. The inert coin cathode is the meeting point for the electrons to interact with oxygen and water to produce more hydroxide ions to keep the anode reaction going.

The aluminium hydroxide $Al(OH)_3$ produced at the anode will eventually build up in the solution (electrolyte), reducing the number of hydroxide ions available to react with the aluminium metal. The battery is likely to stop working after about 20 minutes, but this will depend on the amount of electrolyte available.

Sodium hydroxide electrolyte should produce about 1.0 V per cell. Saline solution electrolyte should produce about 0.7 V per cell.

The vinegar neutralises the OH^- ions as they are produced, which is why it is the worst performing electrolyte. However, sulfuric acid does provide us with a greater voltage output than saline solution. This is because it is causing a different reaction at the cathode, to produce hydrogen gas and aluminium sulfate rather than aluminium hydroxide.

- ***Reaction at aluminium foil anode with sulfuric acid solution as electrolyte:*** $2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$

Aluminium metal is difficult to extract from aluminium sulfate, so the sodium hydroxide electrolyte is more sustainable.

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