HOMEMADE BATTERIES
Making and evaluating homemade batteries

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Languages available
English, Slovenian

Summary
Batteries power most of the portable electrical and electronic devices we use. Different types are available, suited for different uses. Batteries convert chemical energy into electrical energy. You can make a battery from a lemon, a piece of zinc and a piece of copper. So why don't we use this instead of buying batteries from shops? In this activity you find out. You also explore other homemade batteries, including a seawater battery made by scientists in the BBC TV programme *Rough Science*. The purpose is to explore the potential of low technology homemade batteries as emergency power supplies.

Activity type H
Use of scientific knowledge and understanding to solve problems
Working in teams to solve problems
Communication
Resource/budget management
Time and workload management

Techniques

Field
Electrochemistry

Time
Practical lessons: 600 minutes
Theory lessons: 120 minutes
Out of class time: 360 minutes

StandardBase procedures
None

StandardBase techniques
None

Other resources
Zavod za šolstvo, Ljubljana (The National Education Institute of the Republic of Slovenia), http://www.zrss.si/

Other resources are listed in the activity.

Student's document

HOMEMADE BATTERIES: Making and evaluating homemade batteries

Batteries power most of the portable electrical and electronic devices we use. Different types of batteries are available, suited for different uses. In a battery, chemical energy is transformed into electrical energy. You can make a battery from a lemon, a piece of zinc and a piece of copper. You can replace the lemon with a potato and still produce electricity. In fact, a whole variety of fruit and vegetables work and so does using different metals. So why don't we use these instead of buying batteries from shops?

Your brief
Your brief is to carry out research on low technology homemade cells and batteries and write a report on their potential as low voltage electricity supplies.

Task 1
Find out about commercial cells and batteries (a battery is a number of cells connected in series). Make brief notes about the types available, together with their uses, price and life expectancy. Also make notes on their care and maintenance, and their disposal and recycling. Finally, find out about the importance of internal resistance of a cell or battery (you will investigate internal resistance in a later task). Obtain a copy of **Study sheet***: Commercial cells and batteries*. This will help you to plan and organise your research.

Task 2
Making cells and batteries from bits of metal and fruit and vegetables such as lemons and potatoes is well known. The metals are the electrodes and the fruit and vegetables provide the electrolyte. Significant voltages are produced, but only tiny currents because of their high internal resistance. Remember, however, that internal resistance is only one feature of a useful cell or battery. The most important feature is fast electrode reactions. Other important features include: high surface area of electrodes, solid state electrode reactions that avoid concentration polarisation, small changes in volume during operation and low corrosion of electrodes.

In this task you explore homemade cells and batteries and make some initial observations about their potential use and limitations. Obtain a copy of **Student sheet***: Simple electrochemical cells* for information to help you with this part of the activity.

Task 3
Investigate the factors that determine the output (voltage and current) from some simple cells. These should include:
- electrolyte - nature and concentration
- electrodes - nature, surface area and distance apart.

Obtain a copy of **Student sheet***: Cell design*.

Task 4
You learned earlier that internal resistance was one of the important factors in determining the usefulness of cells and batteries. Try determining the internal

resistance of some cells, using the **Student sheet***: Determining internal resistance* to guide you.

Task 5

In task 2 you investigated cells connected in series. Now find out the effect of connecting them in parallel. Obtain a copy of **Student sheet***: Series or parallel* for information to help you.

Task 6

Bring your ideas together by making and testing a 'seawater battery' and comparing it to a battery made from Daniell cells. Obtain a copy of **Student sheet***: A useful homemade battery?* to help you. Estimate the cost of making such a battery.

Task 7

An important feature of a cell or battery is how long it will work for. Some are 'single use' and not rechargeable. Others can be recharged, but are more expensive. The specifications for a battery include its battery capacity. This is usually given in milliampere hours (mA h). Determine the battery capacity of one or two commercial batteries (**Student sheet***: Battery capacity*) and compare them with the battery capacity of one or two of your most effective homemade batteries.

Task 8

Write your report about the potential uses of homemade batteries. The target audience is a 'practical aid' advice group who are interested in the potential of low technology homemade batteries as emergency power supplies, especially for use in parts of the world where portable electrical supplies are not readily available.

You need to describe the key features of commercial batteries and what they are used for. You then need to describe the outcome of your investigations into homemade batteries, evaluating their potential as power supplies and making recommendations about further work to support your initial findings.

Planning

The tasks to complete are described above. The team must decide how best to use the time and resources available. You will need to decide who does what.

Once each member of the team has read the brief and associated information sheets, the team should get together and plan the team's work.
You should allow time for:

- accessing information via the Internet and/or paper-based resources
- carrying out practical work
- team meetings to check progress and share findings (perhaps an initial 30 minute meeting with three further meetings at appropriate times during your work)
- writing the report.

Remember, a risk assessment must be carried out before starting practical work.

Your findings
In support of your report you should keep a file containing:
- notes summarising the results of your information searches, including annotations that show how you compared information from different sources
- results from practical work, indicating work you did and results that were obtained by other members of your team
- key points from discussions you had with others in your team.

Student self assessment
This activity was about using scientific knowledge and understanding to solve problems, working in teams to solve problems, communication, time and workload management and resource/budget management. For each case, write 50-100 words explaining:
- what scientific skills and knowledge you used and how effectively you used them
- how you worked as a team, giving examples of how you supported others in your group or were supported by them
- how you used good communication skills
- how you managed resources and budgets
- how you managed your time and workload.

Student study sheet: Commercial cells and batteries

What's available?
Many different types of cells and batteries can be bought.

Use a combination of visits to shops and Internet research to find out which types of cells and batteries are on the market.

To get started, look at http://en.wikipedia.org/wiki/List_of_battery_sizes. This gives a good summary of the range of batteries available commercially.

Assign each cell or battery you find as: non-rechargeable (sometimes called 'single use') or rechargeable.

You will need to search other sources for more information. One good website from which to gather information is http://www.battery-force.co.uk/. You can probably find others.

Here is a typical set of data found via the *Battery Force* website:

Duracell Procell AA/LR6
AA batteries are the most common size of battery used in the UK today. They power a wide range of devices, from audio players and digital cameras to toys and torches. Alkaline technology provides much better value for money than traditional zinc chloride batteries, especially with more demanding applications such as CD or MP3 players.
Battery capacity: 2600 mA h Battery technology: Alkaline (Single use)
Voltage: 1.50 V
Diameter: 14.5 mm Height: 50.0 mm
Weight: 24.0 g

Note: Battery capacity is proportional to the electrical energy a battery can deliver over a period of time. At a steady discharge, it is measured in milliampere hours (mA h). So, for a non-rechargeable battery, the higher the value, the longer the battery life. Milliampere hours (mA h) are calculated by multiplying the current (in milliamperes) by time (in hours) the current is drawn.

Comparing
For each cell or battery you found, record as much of the following information as you can find:

- brand name
- cost
- voltage
- items it may be used to power
- battery capacity
- size (dimensions and mass)
- the chemical reactions that take place to produce electricity

Construct a suitable table to record your findings and make it easy to compare one cell or battery with others.

Care and maintenance
Now make some general notes about the care and maintenance of cells and batteries - in other words, how to get the best out of them.

Disposal and recycling
All cells and batteries eventually stop working effectively. They need to be disposed of. Explain why this presents an environmental problem and make some brief notes on the disposal and recycling of cells and batteries.

Internal resistance
Finally, find out what you can about what is meant by a cell's 'internal resistance'.

Student sheet: Simple electrochemical cells

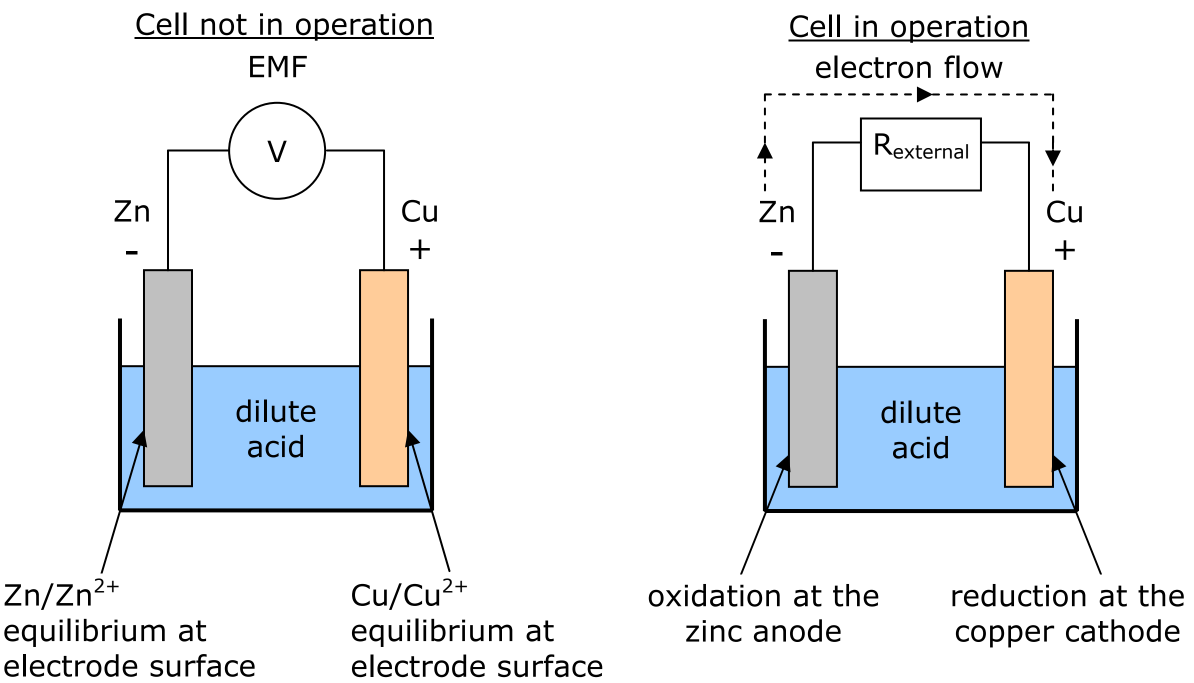
What is an electrochemical cell?
An electrochemical cell consists of two electrodes and one or two electrolytes. Chemical reactions result in the movement of electrons in the external circuit

- from one electrode where the oxidation takes place (the anode)
- to the other where the reduction takes place (the cathode).

This movement of electrons is caused by the electromotive force (EMF).

A 'vinegar' cell
If you put a piece of copper and a piece of zinc into dilute acid and connect them to a high internal resistance (10^7 Ω) multimeter, the EMF can be measured. It is about 1 V.

You can make a simple cell by using vinegar as the acid:
Pour some vinegar into a small beaker. Place a piece of copper and a piece of zinc (strips or wire) into the acid with the ends above the beaker. Connect to a high resistance multimeter and measure the voltage (set meter to DC volts).



These reactions take place:
$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
Electrons move from the zinc electrode to the copper electrode in the external circuit, where:
$2H^+(aq) + 2e^- \rightarrow H_2(g)$
or reduction of the dissolved oxygen, depending on the cell current.

However, hydrogen will also be produced at the zinc electrode due the direct reaction between zinc and the acid even if the electrodes are not connected outside the cell (corrosion).
$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$

The chemistry can become complex. The key point is that we can convert chemical energy into electrical energy using some very simple devices dividing redox reaction into separated half reactions at two different electrodes. And that's what you will look at next.

Electricity from a lemon, copper and zinc
You will need:
- lemons
- copper wire or strip
- zinc wire or strip
- a small beaker
- LED
- connecting leads
- a high internal resistance ($10^7\ \Omega$) multimeter

Important: When measuring current, you will find that, when the circuit is completed, the current decreases as the battery is 'drained'. So make your measurement and immediately disconnect the meter to break the circuit.

Lemon cell
Push one piece of copper and one of zinc into a whole lemon. It helps if you roll the lemon around in your hands, gently squeezing it, before you insert the electrodes.
Connect the multimeter and measure (a) voltage (set multimeter to DC volts), (b) current (set multimeter to DC milliamps).
Try lighting a LED using the cell.

Lemon battery
Now make a lemon battery by connecting your cell in series with three or four other cells made by people in your group. Find out how many cells must be connected in series to make a LED light up, even if only dimly.
You do not need to use a whole lemon for each cell. A segment will be fine, but make sure there is no lemon juice connecting any of the segments to one another.
Note: You could also try using a potato, or other vegetables or fruit, in place of the lemon.

Conclusions
At this stage, write some brief notes about the voltage and current that can be obtained from these homemade cells and batteries. You can refer to these when writing your final report.

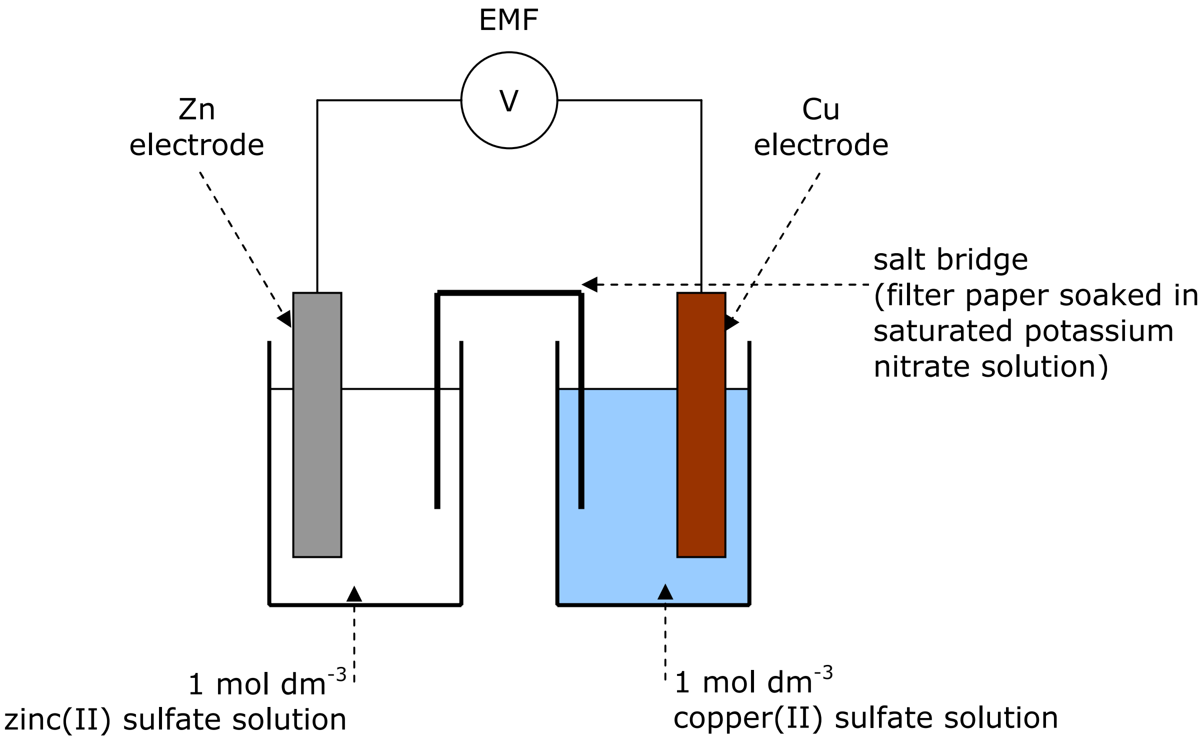
Think about these three questions when writing your notes:
- What voltages can be obtained from cells and how can these be increased to produce higher voltages?
- What currents can be obtained and how, if at all, does this limit the usefulness of the homemade cells and batteries?
- What can you deduce about the internal resistance of the homemade cells and batteries?

Also, what other problems are beginning to emerge in terms of the usefulness of these cells and batteries. How might they be overcome?

Student practical sheet: Cell design

The simple cells you made (**Student sheet**: *Simple electrochemical cells*) produce measurable voltages but a negligible current. This is due to their high internal resistance.

Here is a design for an electrochemical cell with a lower internal resistance. It's called a Daniell cell.



It consists of two half cells:

- copper in copper(II) sulfate solution
- zinc in zinc sulfate solution.

These are connected by a salt bridge.

Making a Daniell cell

You will be provided with:

- strip of copper
- strip of zinc
- 1 mol dm^{-3} copper(II) sulfate solution
- 1 mol dm^{-3} zinc sulfate solution
- piece of filter paper soaked in saturated potassium nitrate solution (this is the salt bridge) or agar-agar tube
- small beakers

Use a high resistance multimeter to measure the voltage.

Describe the differences in the construction of this cell and those you made using **Student sheet**: *Simple electrochemical cells*.

- Write equations for the reactions that occur at each electrode.
- Explain the purpose of the salt bridge.
- How does the voltage produced by this cell compare with those produced by the simple electrochemical cells you made before?

Investigating cell design

You will be provided with:

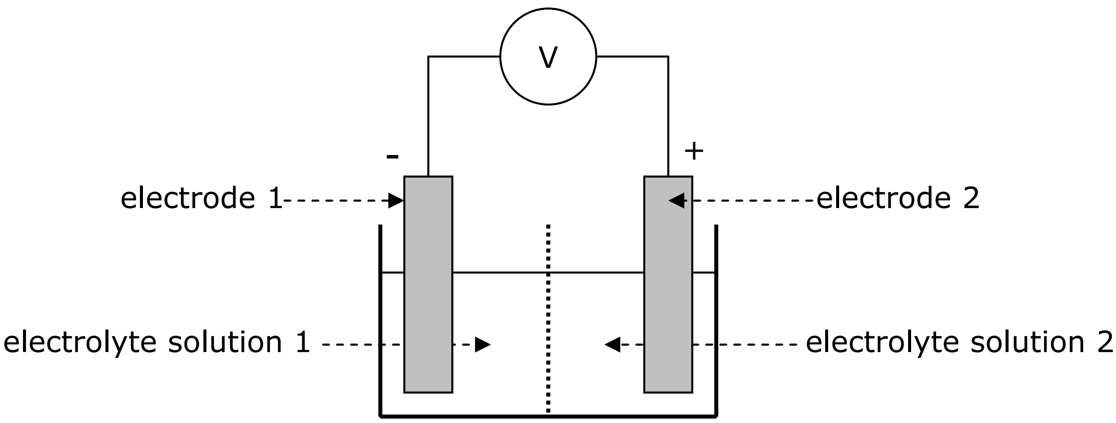
- electrode materials: aluminium, zinc and copper (where possible, as wire, rods and foil)
- 1 mol dm^{-3} solutions of their ions (Al^{3+}, Zn^{2+}, Cu^{2+}).

You will have access to the usual laboratory equipment and a high resistance multimeter.

You might (a) try any combination of these electrodes; (b) vary the concentration of the metal ions.

Voltage

Make a range of simple electrochemical cells and measure the voltage (EMF) that each produces.



Costs

Estimate the cost of materials required to make the cells you tried. Use a chemical supplier's catalogue, either a hard copy or online.

Results

Record your results in a table similar to this:

electrode 1	**electrolyte solution 1 mol dm^{-3}**	**electrode 2**	**electrolyte solution 2 mol dm^{-3}**	**EMF V**	**cost of cell €**

Student sheet: Determining internal resistance

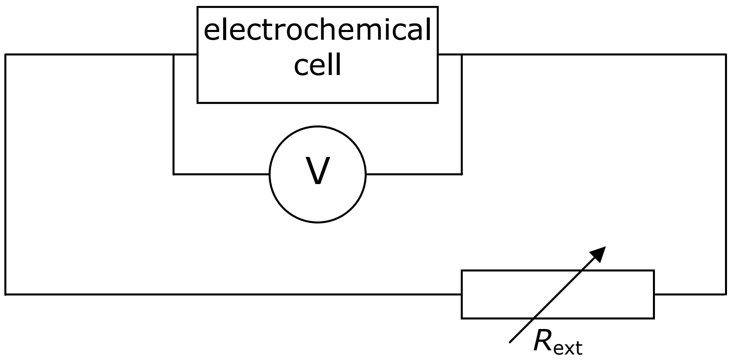
Determining the internal resistance of a cell

This is how you can measure the internal resistance of a cell or battery (R_{cell}).

In addition to the materials and equipment you used to make and test the simple cells (**Student sheet**: *Simple electrochemical cells*) you will need a 10^7 Ω resistance substitution box.

Procedure

1. Set up the circuit shown below.

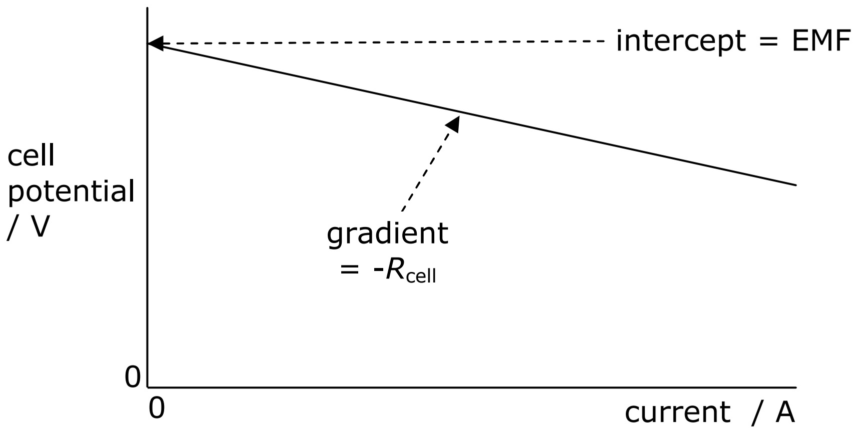


2. Set the resistance substitution box to 10^7 Ω. This is the load resistance (R_{ext}). Record the current and voltage values in a suitable table.

3. Reduce the load resistance to 10^4 Ω in ten steps. Each time, record the value of voltage (U). Remember that the voltage you measure is not the EMF but the output voltage (cell potential). There is no need to measure the cell current because it can be calculated from:

$$I = \frac{U}{R_{ext}}$$

4. Plot a graph of U against I.



5. From the graph, calculate:
a. the EMF of the cell (the theoretical voltage output when no current is flowing)
b. the internal resistance of the cell (R_{cell}).

Student sheet: Series or parallel?

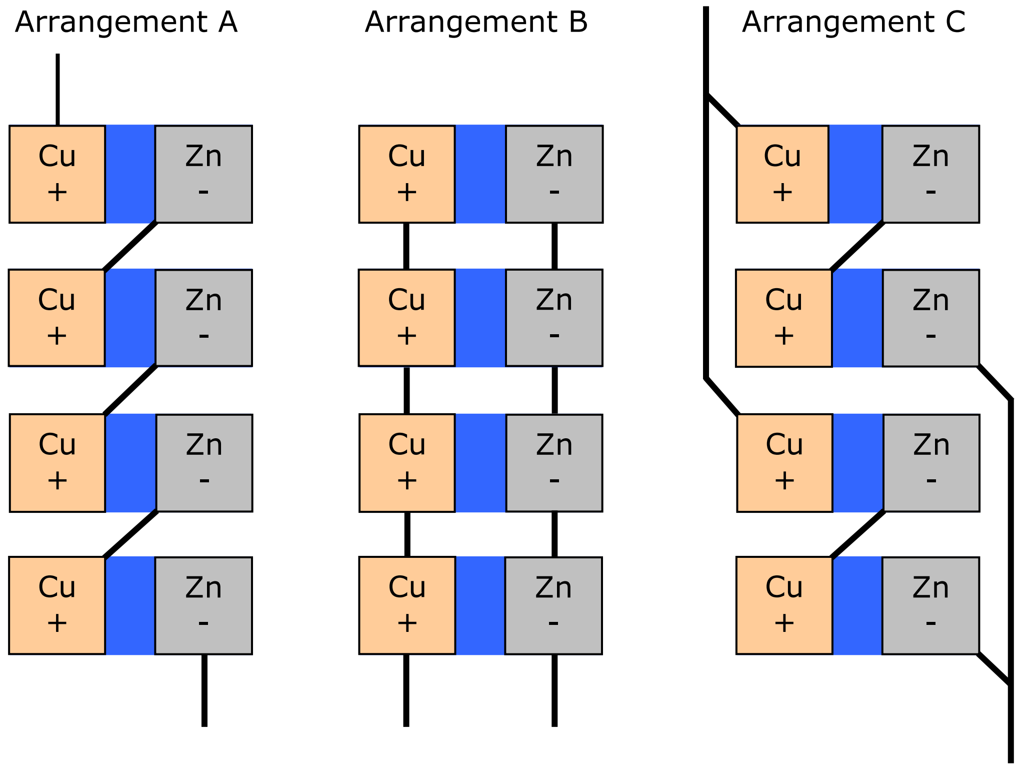
Cells may be connected in series to make batteries. You have used ***Student sheet**: Simple electrochemical cells* to investigate this. However, cells could also be connected in parallel.

Imagine you have four cells. Each cell can produce a voltage of *U* volts and a maximum current of *I* amps.

- Connected in series, the four cells will produce:
  4 x *U* volts a maximum current of *I* amps
- Connected in parallel, the four cells will produce
  U volts a maximum current of 4 x *I* amps

Vinegar cells in parallel and in series
Check this out yourself by assembling four vinegar cells (**Student sheet**: *Simple electrochemical cells*).

Write down the voltage you expect from a single vinegar cell. Now look at the wiring diagrams below and, for each battery, predict the voltage produced.



(This is an unconventional figure showing the + electrode on the left side.)

Connect the vinegar cells and measure the voltage for each using a high resistance multimeter (set to DC volts). How do these compare with your predictions?

For each wiring sequences, try lighting a LED. Remember - the brighter the LED, the greater the current that is passing.

Note: You may try measuring the current. If you do, however, make sure there is an external resistor in the circuit.

Student sheet: A useful homemade battery?

Rough Science

In the BBC television programme *Rough Science*, a team of scientists are cast away in a remote area and challenged to make scientific devices from a limited supply of materials. You can read about the series at http://www.open2.net/roughscience/
In one series, the scientists land on the island of Zanzibar. One challenge was to make a light that would help somebody lost at sea to be spotted by rescuers. Dr Jonathan Hare took up the challenge. You can read his diary at http://www.open2.net/roughscience5/lost_at_sea%20_jonathans_diary.html
For detailed information about the seawater battery Jonathon made, see http://www.creative-science.org.uk/sea1.html
The battery is also described in *Education in Chemistry* (January 2006), also online at http://www.rsc.org/Education/EiC/issues/2006Jan/Rough.asp

Comparing a seawater battery and a battery of Daniell cells

- Make the two batteries:
  - a sea water battery
  - a battery consisting of Daniell cells.
- Investigate their versatility and possible applications.
- Work out how much they cost to build.
- Evaluate their usefulness.

Seawater battery

Read the *Rough Science* article and plan your work. You will find it builds on the ideas of cells and batteries you have been investigating. (Note: If your ice cube tray has a different number of compartments to the one described in the article, you will need to adapt the design).

Battery of Daniell cells

Construct a battery consisting of several Daniell cells. You will be provided with an ice-cube tray, several strips of copper and zinc, 1 mol dm^{-3} copper(II) sulfate solution, 1 mol dm^{-3} zinc sulfate solution, filter paper, a saturated solution of potassium nitrate.

Comparing batteries

Try connecting the cells in series and in parallel, in various combinations (see **Student sheet***: Series or parallel?*). For each of the possible combinations, record the voltage produced.

If you want to try powering some electrical devices with your battery, you might be able to use:

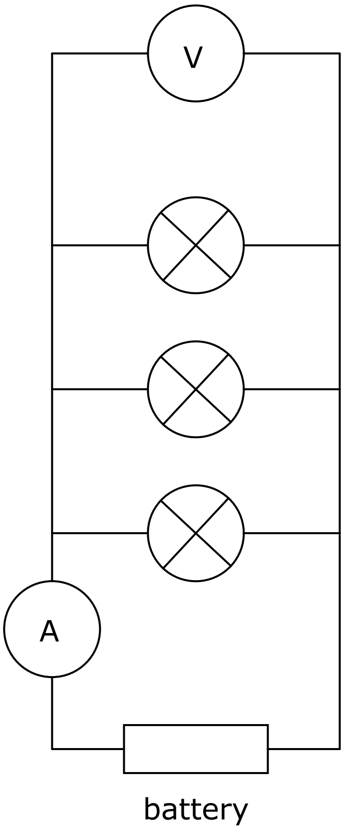
- *Relatively high voltage, low current*
  A simple LED circuit may be used to show the battery working. Use a LED rated for 1.8 V and 0.1 mA.
- *Relatively low voltage, high current*
  Try a low voltage motor. Some motors will run on only about 1 volt but need 10 mA or so in order to turn, e.g.
  http://www.solaronix.ch/products/demonstration/lowcurrentmotor/

Student sheet: Battery capacity

A characteristic property of all batteries is their battery capacity. For example, Duracell *Procell* non-rechargeable batteries have these characteristics:

Type	**Voltage**	**Battery capacity**
AA	1.5 V	2600 mA h
AAA	1.5 V	1200 mA h

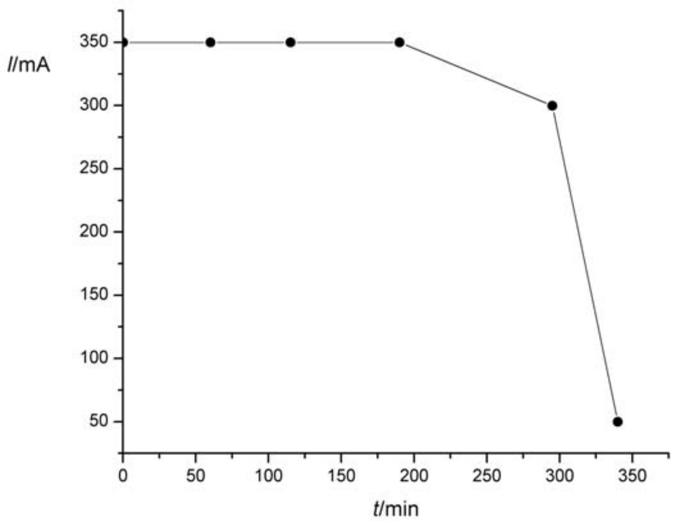
You can investigate the working life of a non-rechargeable battery with the circuit below. Three small lamps are wired in parallel. Voltage and current are measured and recorded at regular intervals over 2-6 hours. The time will be adjusted depending on the batteries and the size of the lamps.



You will need:

- cells and batteries (these may be the ones you made or commercially available products)
- two multimeters (or one voltmeter and one ammeter)
- three lamps
- connecting wires
- battery recharger (if you want to investigate rechargeable batteries)

Here is an example of a current against time:



The battery capacity can be calculated by measuring the current produced and the time it is produced for.

In the example above, a current of 350 mA flows for about 3 hours before it drops significantly (and, therefore, will not provide the required power – the lamps will dim).

Therefore, battery capacity = 350 x 3 = 1050 mA h

Teacher's document

Overview
This is a challenging activity, with much practical work and underpinning theory. Students work in groups to investigate the feasibility of making homemade batteries. The work requires careful time and workload management. It also requires students to cost some of their work.

The work culminates in a report on the potential use of homemade batteries as emergency power supplies.

To do this the team must:
- find out about commercial cells and batteries
- carry out practical investigations into
  - the power provided by simple electrochemical cells
  - the effect of connecting more than one cell in series to make a battery
  - the difference in power supply when cells are connected in parallel as opposed to series
  - battery capacity
- make and test
  - a homemade seawater battery, working out much it costs to make
  - a Daniell cell and a battery consisting of more than one Daniell cell, working out much the battery costs to make and comparing its effectiveness with the seawater battery as a power supply.

The formal report should be supported by:
- notes summarising the results of literature searches, including annotations that show how information from different sources was evaluated
- results from practical work, indicating work they did and which results were obtained by other members of the team
- key points from discussions with others in the team.

Developing students' skills
Learning objectives
Students:
- manage relationships to work effectively with others to solve problems
- communicate effectively to an audience of non-scientists
- manage time and workload effectively
- manage resources and budgets effectively
- use scientific knowledge and understanding to solve problems
- observe, measure, analyse and evaluate scientific data.

Guidance and help
Students will be expected to have practiced the various skills in other activities. This activity brings the skills together in one exercise. Despite their experience, students will still need guidance and help. It is vital that checkpoints are agreed; these may be set by the teacher or the group.
This activity may allow a variety of assessment criteria to be met, according to the course being followed. Observations of practical work and the completed recording sheets and report should provide evidence that can be judged against published grading criteria.

Organising and managing the class
Students work in a group (3-4 would be appropriate). Before embarking on the activity it is vital that all students understand what the outcome needs to be, i.e. the report, supported by their research notes. This might be a short teacher-led discussion at the start of the first lesson.

Depending on the experience and confidence of the students, it may be appropriate for some to work in a larger group, say 6, to share the workload. Such an arrangement, however, is likely to require careful monitoring.

Before commencing work, ensure that each team knows:
- the time within which they have to work, including how much time they are expected to work on the activity outside of laboratory/classroom time
- when laboratory facilities and resource facilities (e.g. learning resources centre or library) will be available.

Groups should be encouraged to include 'group meetings' when member get together to share results, information and ideas.
Here is a summary of the tasks that comprise the activity.

Task 1
There are plenty of websites that can provide the information required. Two that provide a good starting point are:
http://en.wikipedia.org/wiki/List_of_battery_sizes
http://www.battery-force.co.uk/.
There is no need for this task to be done before other work starts.

Task 2
There are several parts to this task. They are quite straightforward, but do require planning and workload sharing. Students make a 'vinegar cell' (later, in task 5, they investigate making batteries by connecting vinegar cells in parallel and in series).

They make a lemon cell and a lemon battery. The purpose is:
- to provide an interesting stimulus for the study of electrochemical cells
- to initiate students' thinking about the apparent ease with which electricity can be produced from everyday materials, given their brief to evaluate low technology batteries as emergency power supplies.

The important outcome of this task is that the students see how simply a cell or series of cells (a battery) can be made. However, they will also find that, while the voltages are measurable, the current is too small to do much useful work. LEDs are designed to work on voltages around 2 V and low current. About three lemon cells in series should make a LED glow dimly.

Task 3
Students investigate factors that determine the output (voltage and current) from some simple cells, including:
- the electrode material (Surface area and distance apart also have an influence, but it is much less significant; however, internal resistance is less, the greater the surface area and the nearer electrodes are to one another.)
- the nature and concentration of the electrolyte.

Task 4
Students determine the internal resistance of some cells.

They should compare:
- at least one cell or battery with high internal resistance, e.g. the vinegar cell and battery and the lemon cell and battery

with
- at least one cell or battery with relatively low internal resistance, e.g. the Daniell cell or commercially-available batteries.

Each pair of students in the team should compare a high resistance cell or battery to a low resistance cell or battery.

Task 5
Students investigate connecting cells connected in series and in parallel. They need to use a high resistance multimeter to measure voltage. The relative magnitude of the current (higher when cells are wired in parallel) can be assessed from the brightness with which the LED glows. The current could be measured, but if it is there must be an external resistor in the circuit. This might be, for example, a small lamp.

The key outcome is that connecting cells in parallel does not increase the voltage, but does increase the current, while connecting cells in series increases the voltage, but does not increase the current.

Task 6
Students make and test a ‘seawater battery’ and a battery consisting of two or more Daniell cells.

Daniell cells have lower internal resistance and provide higher currents. Students should be recognising the limitations of the simply electrochemical cells – high internal resistance resulting in low current.

Task 7
Students use a simple circuit to estimate battery capacity. Each pair of students in the team should compare the battery capacity of a commercial battery (and with that battery’s specification) and a homemade battery.

Task 8
Students write a report about the potential uses of homemade batteries.

It is essential to give the students an idea of structure and to encourage them to write for the intended audience (a ‘practical aid’ advice group interested in the potential of low technology homemade batteries as emergency power supplies). Encourage students to:
- describe the key features of commercial batteries and what they are used for
- describe the outcome of their investigations into homemade batteries
- evaluate the potential of homemade batteries as power supplies (even though the evidence might be quite discouraging)
- make recommendations about further work to support initial findings and gather further relevant data.

Session plan for teachers

Exact timing depends on many factors, but the following is suggested:

- Introduction and checking prior knowledge (30 minutes)
- Initial planning meeting for students (30 minutes)
- Allow time for at least three team meetings during the 18 hours (90 minutes)
- Task 1 (90 minutes)
- Task 2 (90 minutes)
- Task 3 (90 minutes)
- Task 4 (90 minutes)
- Task 5 (120 minutes)
- Task 6 (120 minutes)
- Task 7 (120 minutes)
- Task 8 (210 minutes)

Total 1080 minutes.

Technical notes

Equipment and materials

Simple electrochemical cells

- vinegar
- lemons
- small beaker (e.g. 100 cm^3)
- copper strips or wires
- zinc strips or wires
- connecting leads and clips
- LEDs
- high internal resistance (10^7 Ω) multimeter

Note: When the circuit is completed the current decreases as the battery is 'drained'. Measurements must be made immediately and once taken the meter must be disconnected to break the circuit.

It may help some students if a sample circuit is set up for them to look at before connecting their own.

Cell design

Making a Daniell cell

- strip of copper
- strip of zinc
- 1 mol dm^{-3} copper(II) sulfate solution
- 1 mol dm^{-3} zinc sulfate solution
- piece of filter paper soaked in saturated potassium nitrate solution (this is the salt bridge) or agar-agar tube KNO_3
- small beakers (e.g. 100 cm^3)
- connecting wires and clips
- high internal resistance (10^7 Ω) multimeter

Note: When the circuit is completed the current decreases as the battery is 'drained'. Measurements must be made immediately and once taken the meter must be disconnected to break the circuit.

Investigating cell design

- electrode materials: aluminium, zinc and copper (where possible, as wire, rods and foil)
- 1 mol dm^{-3} solutions of their ions (Al^{3+}, Zn^{2+}, Cu^{2+}). Suitable solutions:

- 1 mol dm^{-3} copper(II) sulfate solution
- 1 mol dm^{-3} zinc sulfate solution
- 0.5 mol dm^{-3} aluminium sulfate solution

Other equipment is as for the Daniell cell.

Determining internal resistance

In addition to cell being tested, students will need:

- connecting leads
- high internal resistance (10^7 Ω) multimeter
- a 10^7 Ω resistance substitution box.

Series or parallel?
Students will need cells made in the **student sheets**, *Simple electrochemical cells* and *Cell design*, which they can connect in series or in parallel. In addition:
- connecting leads
- high internal resistance (10^7 Ω) multimeter
- LED (rated for 1.8 V and 0.1 mA).

If students want to measure the current, they must make sure that there is an external resistor in the circuit.

A useful homemade battery?
Seawater battery
Students need to research the information themselves.

If they follow the guidance in the web reference provided, http://www.rsc.org/Education/EiC/issues/2006Jan/Rough.asp the equipment and materials required are:
- dilute solution for sodium chloride in tap water (made by dissolving a teaspoon of salt in a mug of water, i.e. about 6 g in 200 cm^3 of water). Seawater typically has a sodium chloride concentration of 35 g dm^{-3}.
- 12-compartment (or similar) plastic ice-cube tray
- piece of wood or thick card to support the electrodes; bare copper wire (i.e. no insulation)
- for each cell:
  - 5 cm long galvanised screw
  - pencil lead (2B or softer) or a 'carbon' rod
- connecting wire and crocodile clips (or similar connectors)

Battery of Daniell cells
Students will have made a Daniell cell (for equipment and materials see *Cell design*). They need to make several cells using a plastic ice-cube tray. A 12-compartment tray would allow six Daniell cells to be made and connected in various configurations.

For each cell:
- strip of copper
- strip of zinc
- 1 mol dm^{-3} copper(II) sulfate solution
- 1 mol dm^{-3} zinc sulfate solution
- piece of filter paper soaked in saturated potassium nitrate solution (this is the salt bridge) or agar-agar tub KNO_3
- connecting wire and crocodile clips (or similar connectors)

Comparing batteries
- LED rated for 1.8 V and 0.1 mA.
- low voltage motor

Some motors will run on only about 1 volt but need 10 mA or so in order to turn, e.g. http://www.solaronix.ch/products/demonstration/lowcurrentmotor/

Another place where you can buy LED's and low voltage motors is the Middlesex University Teaching Resource: http://www.mutr.co.uk/

Battery capacity

- cells and batteries (these may be the ones made by the students or commercially available products)
- 2 x multimeters (or one voltmeter and one ammeter)
- 3 x lamps
- connecting wires
- battery recharger (to investigate rechargeable batteries)

Materials and their CAS numbers

copper(II) sulfate solution	7758-98-7
zinc sulfate solution	7446-20-0
potassium nitrate solution	7757-79-1
aluminium sulfate solution	17927-65-0

Testing prior knowledge

1. Look at this list of metals.

gold zinc magnesium copper iron

a. Which one dissolves most readily in 1 mol dm^{-3} hydrochloric acid?
magnesium
b. Which two do not react with 1 mol dm^{-3} hydrochloric acid?
gold and copper
c. Which is least reactive (most positive in the electrochemical series)?
gold

2. Zinc dissolves in _______ copper(II) sulfate solution. The solution becomes _______ in colour and reddish brown copper forms. _______ are transferred from zinc atoms to copper(II) ions. Zinc is _______ to zinc ions and copper(II) ions are reduced to _______. It is a _______ reaction.

Match these words to the gaps in the paragraph above

electrons
paler
redox
blue
oxidised
copper

Zinc dissolves in blue copper(II) sulfate solution. The solution becomes paler in colour and reddish brown copper forms. Electrons are transferred from zinc atoms to copper(II) ions. Zinc is oxidised to zinc ions and copper(II) ions are reduced to copper. It is a redox reaction.

3. Write ionic equations for the reactions that take place between:

a. zinc and copper(II) sulfate solution
$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

b. copper and silver nitrate solution
$Cu(s) + 2Ag^{+}(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$

c. magnesium and 1 mol dm^{-3} hydrochloric acid
$Mg(s) + 2H^{+}(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

Note: answers are given in red. These need to be removed before the test is used.

Testing prior knowledge

1. Look at this list of metals.

gold zinc magnesium copper iron

a. Which one dissolves most readily in 1 mol dm^{-3} hydrochloric acid?
b. Which two do not react with 1 mol dm^{-3} hydrochloric acid?
c. Which is least reactive (most positive in the electrochemical series)?

2. Zinc dissolves in _______ copper(II) sulfate solution. The solution becomes _______ in colour and reddish brown copper forms. _______ are transferred from zinc atoms to copper(II) ions. Zinc is _______ to zinc ions and copper(II) ions are reduced to _______. It is a _______ reaction.

Match these words to the gaps in the paragraph above

electrons
paler
redox
blue
oxidised
copper

3. Write ionic equations for the reactions that take place between:

a. zinc and copper(II) sulfate solution

b. copper and silver nitrate solution

c. magnesium and 1 mol dm^{-3} hydrochloric acid