

“Can” You Really Make a Battery Out of That?

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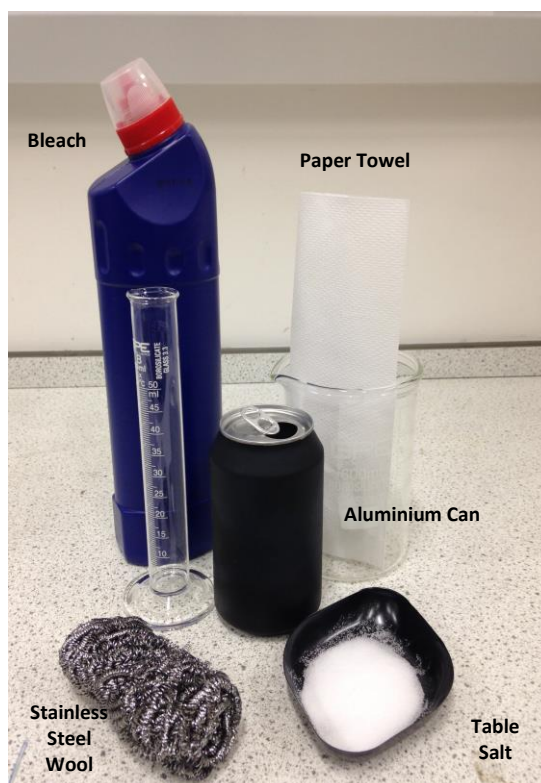
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Abstract

This experiment introduces students to the fundamentals of battery electrochemistry through turning domestic products into batteries. Developed for United Kingdom secondary schools and exam boards, students will learn that the performance of a battery is determined through its design, and chemistry. This simple battery is used to power electrical devices such as light emitting diodes. In addition, this manuscript presents potentiostatic cyclic voltammetry, and chronoampometry results for the battery systems developed within.

Keywords: *High School / Physical Chemistry / Electrochemistry / Half Cell Equations / Metal-Air Battery*



Introduction

Batteries are used in a wide range of applications including: mobile devices, hybrid and electric vehicles, and off grid electrical storage¹. As battery technologies become more prevalent it will be important for future generations to understand how they work.

Experiments are a great way to inspire, and to this purpose, the electrochemistry special interest group of the Royal Society of Chemistry (RSC) has sponsored the design of a battery experiment for United Kingdom (UK) secondary schools which fulfils the requirements of the major UK exam boards general certificate of secondary education (GCSE, ages 14-16), and advanced level (A-level, ages 16-18) qualifications²⁻⁶.

Batteries work through the controlled redox reactions of materials. Here, we develop a battery made from readily available domestic products including an aluminium drinks can. The experiment is based on previous experiments in the chemical education literature⁷⁻¹² with this teaching package consolidating existing works into a simple “ready to use” guide for teachers’ and students aged 14-18 to use in a 50-60 minute classroom lesson, or at home.

The performance of a battery is measured by the voltage and the current it produces. The voltage is a thermodynamic quantity determined by the chemistry. The current depends on the rate of chemical reactions, the batteries internal resistance, and the materials used in its construction; all of which can be modified through design. We present an experiment that allows students to develop an understanding of these concepts.

The Experiment

Part 1 – Construction of an Aluminium Air Battery

This section describes the construction of a battery made from products obtained from a typical supermarket. *Table 1* contains the dimensions, typical chemical composition, and estimated price in GBP of the components needed to assemble the battery.

Table 1: list of components, estimated costs, dimensions, and chemicals needed to construct the battery.

Component	Dimensions	Typical Chemical Composition	Estimated Cost (GBP)
Aluminium Can ¹³	330 – 500 mL	Al	£ 0.75 - 1.00 per can
Stainless Scrubber ¹³	Steel 20 g	~12-14% Cr, ~0.20-1% Mo, >2% Ni, ~0.1-1% C, ~84% Fe	£ 1.00 per scrubber
Paper Towel ¹³	Kitchen ~ 15 x 25 cm	N/A	£ 1.50 per role
Domestos® Household Bleach ¹³	100 – 300 mL	5vol% NaClO, <5vol% NaOH, <5vol% Amines, C ₁₂₋₁₈₋ alkyldimethyl, N-oxides	£ 5.00 per 750 mL bottle
Aluminium cooking foil ¹³		Al	£ 8.00 per role
Salt ¹³	100 – 300 g	NaCl	£ 2.00 per 750 g
Sodium Hydroxide ¹⁴	<1 g	NaOH	£ 24.00 per 500 g
Distilled Water	100 - 300 mL	H ₂ O	N/A

It is found that battery performance can vary with the bleach used in the experiment. Some products instantaneously react with the aluminium. All experiments were carried out with Domestos® original bleach.

The battery anode is made from a 330 mL aluminium drinks can that is carefully prepared by removing the end with the “stay-tab ring opener” with a can opener and scissors. This exposes the internal aluminium surface, which is used in the electrochemical reactions. This is the most hazardous part of the experiment due to the sharp edges left on the can. These

must be removed using scissors, and filed smooth using wet and dry sanding paper. Instructors may wish to prepare cans before the class.

The internal aluminium surface is cleaned and “roughened” with wet and dry sanding paper removing the protective epoxy resin layer from the inside of the can. The cathode is prepared using one 20 g stainless steel scrubber, typically used for kitchen cleaning. This is wrapped inside a 15 cm x 25 cm piece of paper kitchen towel. This separates the anode and cathode preventing short circuit. The stainless steel scrubber, wrapped in paper towel, is then placed inside the aluminium can, as illustrated and pictured in *Figure 1*.

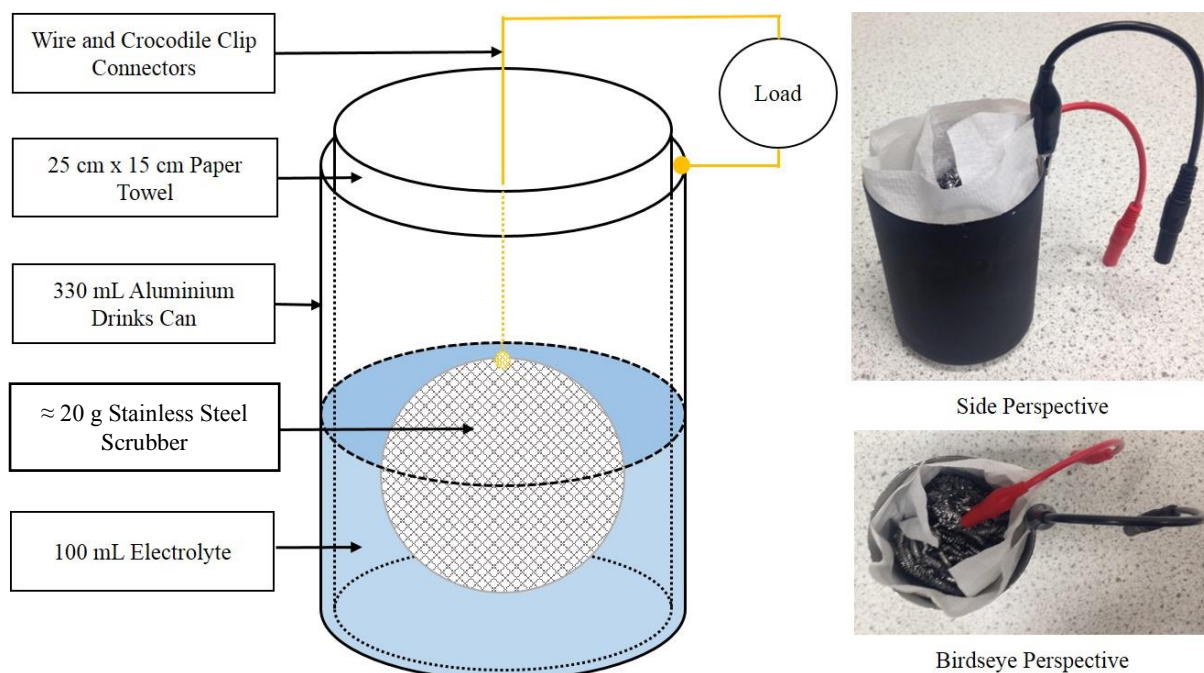
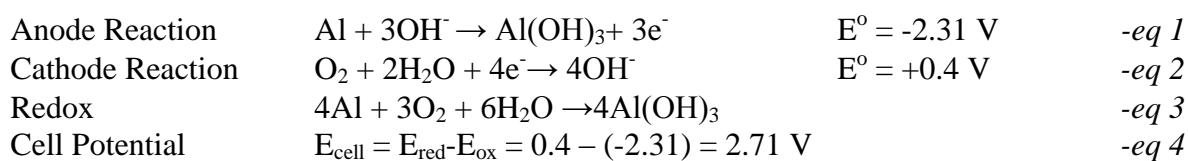


Figure 1: Schematic and pictures of an aluminium can battery made from a 330mL soft drinks can.

A 100mL aqueous solution of 2M NaCl and 0.03M NaOH is added as an electrolyte, creating an aluminium air battery. NaOH helps to remove the Al_2O_3 passivation layer on aluminium¹², and reduces the over-potential of the oxygen reduction reaction (ORR) taking place at the cathode¹⁵. The electrolyte is made by dissolving ~11.6 g of NaCl and ~0.13g of NaOH in 100 mL of distilled water.

Students should determine the electrochemical half-cell equations, and the theoretical voltage (E^0) of the cell. These are outlined below in *equations 1-4*⁷. E^0 is calculated at 2.71V.



Students will record the open circuit voltage (V_{oc}) and short-circuit current (J_{sc}) of the cell using a voltmeter and ammeter. The negative (black wire) of the voltmeter/ammeter should

be attached to the aluminium can, while the positive (red wire) should be attached to the stainless steel scrubber. Students will measure a positive voltage and negative current. By approximating the can as a perfect cylinder or radius $r \approx 3.32$ cm, the internal surface area of the aluminium anode can be calculated. This allows the current to be expressed as a current density in units of mAcm^{-2} . Details of these calculations are provided in the *Teachers' Notes*. When 100 cm^3 of electrolyte is added to the can, the surface area of the aluminium anode is $\sim 95 \text{ cm}^2$. The performance of the cell is very poor. It is only possible to achieve an instantaneous J_{sc} of $\sim 0.6 \text{ mAcm}^{-2}$, while the V_{oc} is measured as $\sim 0.8 \text{ V}$.

Students should explore reasons why the cell doesn't produce the theoretical voltage (E°). Some suggestions include: the parasitic side reaction of water with the aluminium (which evolves hydrogen at the anode), and the large internal resistance of the cell due to the large diffusion distances between the anode and cathode (estimated as $0.2 - 3 \text{ cm}$).

Part 2 – Improving Current and Voltage by Changing Cell Chemistry

The performance of the cell can be improved by changing the chemistry. The electrolyte is replaced with 100mL of house hold bleach containing 5 vol% sodium hypochlorite (NaClO). NaClO acts as an oxidising agent, providing an alternative source of hydroxyl ions. This increases the cathode potential and improves the rate of chemical reaction. The addition of table salt (NaCl) to the bleach further improves its ionic conductivity. NaCl should be added to bleach in the ratio of 10 g of NaCl per 100 mL of bleach.

Students should re-write the half-cell equations and re-calculate E° . These are outlined below in *equations 5-8*. E° is calculated at 3.21 V .

Anode Reaction	$\text{Al} + 3\text{OH}^- \rightarrow \text{Al}(\text{OH})_3 + 3 \text{e}^-$	$E^\circ = -2.31 \text{ V}$	-eq 5
Cathode Reaction	$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Cl}^- + 2\text{OH}^-$	$E^\circ = +0.9 \text{ V}$	-eq 6
Redox	$2\text{Al} + 3\text{ClO}^- + 3\text{H}_2\text{O} \rightarrow 2\text{Al}(\text{OH})_3 + 3\text{Cl}^-$		-eq 7
Cell Potential	$E_{\text{cell}} = E_{\text{red}} - E_{\text{ox}} = 0.9 - (-2.31) = 3.21 \text{ V}$		-eq 8

Students will re-measure the V_{oc} and J_{sc} of the cell. When 100 cm^3 bleach and 10g of NaCl is added to the cell, it is possible to achieve an instantaneous J_{sc} of $\sim 2 \text{ mAcm}^{-2}$, while the V_{oc} is measured as $\sim 1.0 \text{ V}$.

Part 3 – Improving Total Cell Current through Design

The total current of the cell can be further improved by increasing the surface area of the anode. This can be achieved by rolling additional aluminium cooking foil into the can as pictured in *Figure 2*. A piece of $20 \text{ cm} \times 30 \text{ cm}$ aluminium foil is folded in half to make a $10 \text{ cm} \times 30 \text{ cm}$ sheet. Aluminium cooking foil typically has a shiny side and a non shiny side. It is recommended that the foil is folded so that the non-shiny side is on the outside. A $15 \text{ cm} \times 25 \text{ cm}$ piece paper towel is placed on-top of the foil, so that it is in the centre, and there is 2.5

cm of paper either side of the foil. This is followed by a stainless steel scrubber, and a second 15 cm x 30 cm piece paper towel. This creates a “sandwich” like structure. The “sandwich” is then rolled; with the aluminium foil forming the outer most layer. It is vitally important that the aluminium foil does not touch the stainless steel scrubber. The roll is then placed inside the can so that the aluminium foil and can make electrical contact. Wires are then connected to the can and scrubber in accordance with the diagram in *Figure 1*.

When an electrolyte mixture consisting of 100mL of bleach and 10g of NaCl is added, a total J_{sc} of ~ 450 mA can be achieved. This is in contrast to a total J_{sc} of ~190 mA measured when 100mL of bleach and 10g of NaCl is added to the cell design presented in **Part 2**.

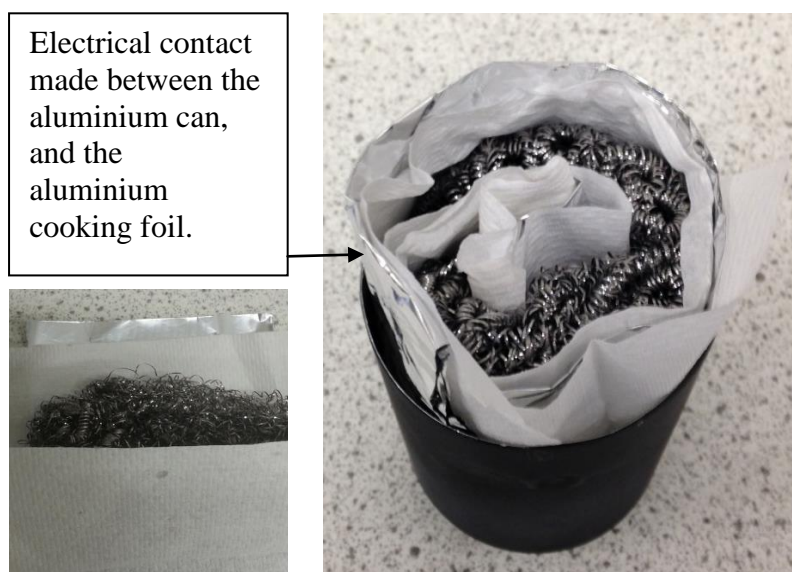


Figure 2: Bottom left: Image of the aluminium foil, paper towel, stainless steel scrubber, paper towel “sandwich”, which is rolled and placed into the aluminium drinks can.

Part 4 – Electrochemical Performance and Powering Light Emitting Diodes

Different battery designs were tested using potentiostatic cyclic voltammetry (CV) and chronoamperometry. Potentiostatic CV is a technique that measures the cell current with respect to an electrode potential which varies with time. This can be used to identify the electrode potential at which the maximum current, and hence maximum power occur. A scan rate of 100mVs^{-1} was used to measure the current of the battery as the electrode potential was varied between $0.8\text{V} \rightarrow 0\text{V} \rightarrow 0.9\text{V} \rightarrow 0.8\text{V}$. The current was recorded every 2.5 mV giving 40 data points per 100 mV.

The battery designs from **Parts 2 and 3** were tested with an electrolyte mixture consisting of 100mL of bleach and 10g of NaCl. The power of the battery is calculated by multiplying the voltage by the current. *Figure 3* plots the magnitude of the average current and average power vs voltage curves for the two different designs. Full details of the experimental method can be found in the *Teachers' Notes*.

Chronoampometry was used to measure the cell current at a fixed electrode potential over time. The electrode potential was fixed to 0.43V, which is approximately the potential at which the maximum power for the bleach battery presented in **Part 2** is obtained. The current was recorded every second over 1800 s (0.5 hr). The average power and the total work done by the cell were then calculated. A full description of the chronoampometry experimental method can found in the *Teachers' Notes*. The average power and the total work done by the cells are recorded in *Table 2*.

The CV and chronoampometry results show that the design presented in **Part 3** has a significantly better short circuit current and maximum power. When any two aluminium bleach-batteries are connected in series, enough voltage is produced to illuminate red or orange LEDs.

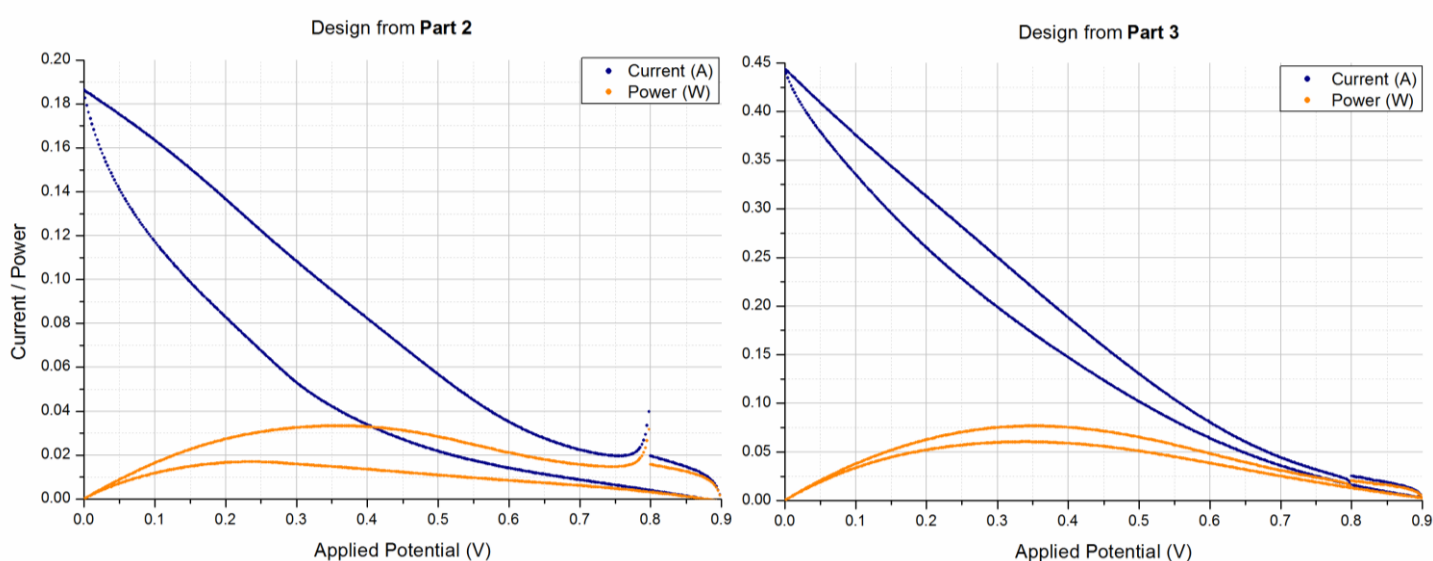


Figure 3: Average potentiostatic cyclic voltammetry, and voltage power plots of the different aluminium can battery designs. Left: battery design from **Part 2** Right: battery design from **Part 3**

Table 2: Average power and the total energy results for two the aluminium can battery designs.

System	Steady State Voltage (V)	Average Cell Power (mW)	Total Work Done (J)
Aluminium can, stainless steel scrubber, paper towel, 100mL, bleach, 10g salt	0.43	11.6	21
Aluminium can, stainless steel scrubber, paper towel, aluminium foil roll, 100mL bleach, 10g salt	0.43	20.3	37

Conclusion

With a growing interest in batteries for delivering a cleaner energy future it is important to design an appropriate battery experiment for UK schools in order to inspire the next generation of scientist and engineers. To this purpose, a simple battery experiment has been designed and tested.

Associated Content

- GCSE student lab script ages 14 -16: lab script, questions, and answers, for a 1 hour classroom lesson.
- A-level student lab script ages 16-18: lab script, questions, and answers, for 2 x 1 hour classroom lessons.
- Teachers' Notes: supporting calculations, experimental setup, hazards.
- Teachers' slides: A short set of slides introducing battery chemistry.

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