The Building Blocks of Battery Technology:

Using modified tower block game sets to explain and aid the understanding of rechargeable Li-ion batteries

Educators Guide

Create - Explore -Understand

The Battery Jenga demonstration can complement teaching in this area and draw on multiple topics. These activities are appropriate to secondary school education and up.

Produced and Written by E. H. Driscoll, R. Patchett and
P. R. Slater, University of Birmingham, UK

July 2020

Preface

Li-ion batteries are everywhere: mobiles phones, laptops and in more recent years, electric vehicles. With a technology now so widely accesible, it is paramount for the understanding behind this type of rechargeable battery to be accessible to not only school children but also to the general public. However, there are a lack of educational resources to help understand this area, in addition, to electrochemistry (which drives the battery operation) being cited as a challenging topic for students to understand.

With this in mind, we have developed a hands on demonstration to help students learn about the key components within this type of battery highlighting the key characteristics and how they operate with a series of demonstrations. The demonstration makes use of tumbling tower sets, such as Jenga, with all items easily accessible and at a relatively low cost.

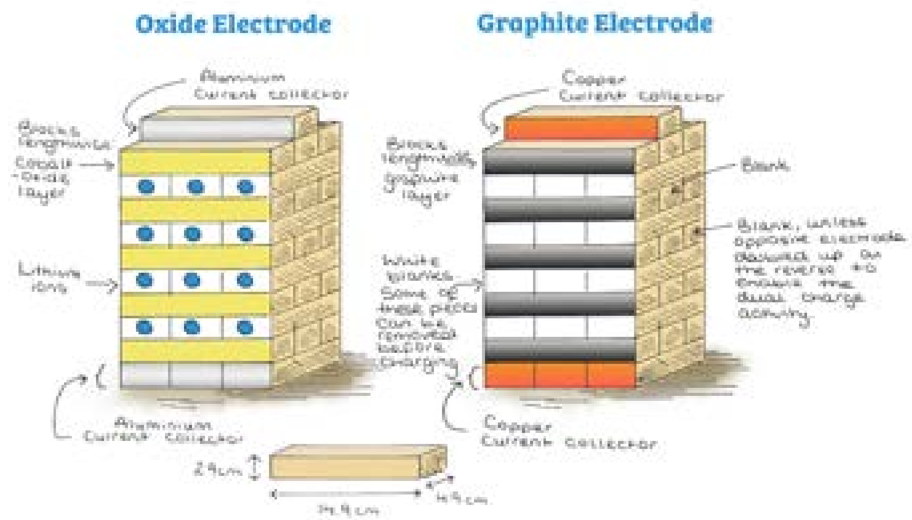
This education guide will help provide the reader or nominally the educator in how to produce these 'Battery Jenga' sets and how to run the associated demonstrations in explaining battery operation and other key features such as rate of charge and degradation. For the educator in mind, battery technology for secondary school children can be related to electrochemical potentials, redox potentials and reaction favourability.

Information taken from recent publication in ACS Journal of Chemical Education titled "The Building Blocks of Battery Technology: Using modified tower block games to explain and aid the understanding of rechargeable Li-ion batteries; E. H. Driscoll, E. C. Hayward, R. Patchett, P. A. Anderson and P. R. Slater".

Table of Contents

1. Battery Jenga Diagram Schematics and Item Lists

1.1. Larger classroom set (0.6 m high)

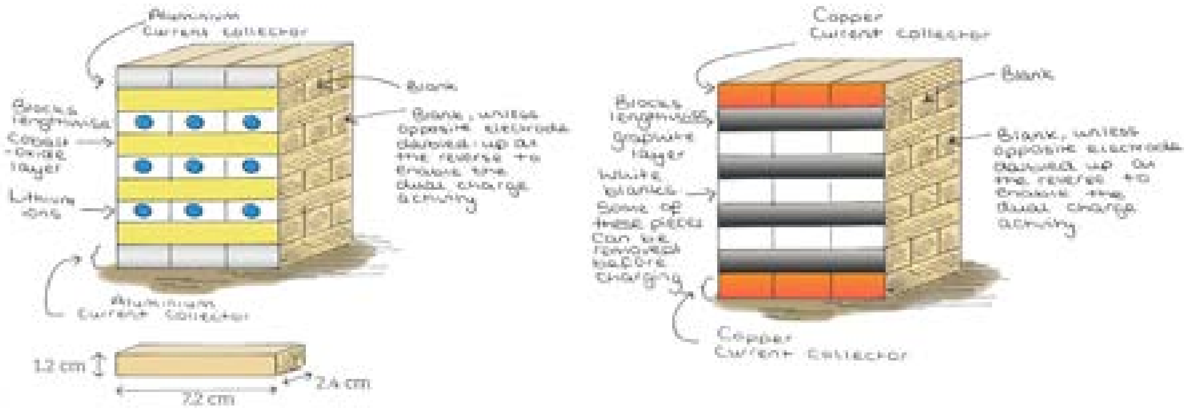


Item list:

Jumbo Hi-Tower in a Bag, Builds from 0.6 Metres up to 1.5 Metres High in Play	£35.45
20 Sheets White Waterproof A4 Vinyl Matt Self Adhesive Sticker Quality Inkjet Printable	£14.99

Prices correct as of May 2020.

1.2. Small set (54 piece set, 21 cm high)



Item list:

My Traditional Games Tumbling Tower 54 Wooden Pieces‡	£5.98
5 Sheets White Waterproof A4 Vinyl Matt Self Adhesive Sticker Quality Inkjet Printable	£5.99

Prices correct as of May 2020.

If you aren't able to get hold of sticker paper, print out onto printer paper and use PVA glue to affix to the blocks, or alternatively you could paint the blocks.

Note you will need access to a printer to print out the templates.

2. Video Demonstrations

Additional videos to support the instruction of the demonstration have been prepared. They can be accessed via the youtube links below or via a QR code reader. The reader can be downloaded from an application store for smart phone devices.

Video A - Demonstration video with original painted set.

https://www.youtube.com/watch?v=g6_ETgt2ME0&t=24s

Video B - Demonstration video with tactile set.

https://www.youtube.com/watch?v=PoeM-7E1pDA

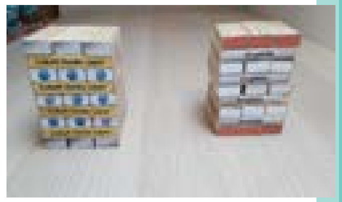
Video C - Demonstration video with tactile set with the added voiceover.

The voiceover provides explanation for the demonstrations, in addition to added information and tips for educators whilst running this activity.

https://www.youtube.com/watch?v=DcgWkGxoh48

3. Makers Guide Videos

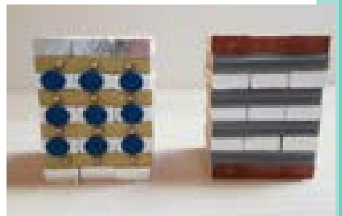
Makers Guide: Sticker Template



Short video showing step-by-step how to produce the sticker version of the small Jenga set.

Activity time - ca. 30 minutes.
https://www.youtube.com/watch?v=wA42iFt_YFc&t=3s

Makers Guide: Tactile Set



Longer video showing step-by-step how to produce a tactile equivalent of the small Jenga set. Multiple materials are required for this.

Activity time - ca. 1 hr 30 minutes up to 2 hours
https://www.youtube.com/watch?v=7mQ_R18QGo0

RSC Top of the Bench, Final, Demo lecture (Jan. 2020)

"The visual demonstration with the jenga blocks really helped my understanding of how a lithium-ion battery works with the movement of lithium-ions into the layered graphite structure."

"I really enjoyed the battery jenga demonstration and thought it was cool how it taught so many different aspects of battery chemistry and how it could be used to explain the basic structure of lithium ion electrodes to a secondary school class, but also initiate greater discussion in university about things like the importance of redox chemistry in the cell."

CoCoMAD 2019 (July 2019)

Manchester Museum of Science and Industry (Nov. 2019)

"Overall I think the repeated disassembly and reassembly of the jenga structure was a great way to demonstrate battery cycling."

4. Set Up Instructions

4.1. Intructions

Split your Jenga in half, one half will be your oxide electrode and the other the graphite electrode.

- Cut out all of the stickers.
- The two electrodes will require the following stickers that represent the following parts of the battery:

Electrode	Sticker	Battery Component
Oxide Electrode		Cobalt oxide layer
		Lithium ion
		Alumnium current collector
Graphite Electrode		Graphite layer
		Empty space between the graphite layers
		Copper current collector

- Peel off the backing paper of the stickers and attach to the blocks (each block should only have one sticker on – see sticker on the side of the Jenga box for guidance on assembly).

Next, build your two electrodes:

Oxide Electrode	Graphite Electrode
1. Three aluminum current collectors. 2. One cobalt oxide layer with two blanks. 3. Three Li-ion blocks. 4. Repeat steps 2 & 3 until you've used all stickers for this electrode.	1. Three copper current collectors. 2. One graphite layer with two blanks. 3. Three white blank blocks. 4. Repeat steps 2 & 3 until you've used all stickers for this electrode.

Note: your set-up may vary depending on the number of piece set you have. If you have fewer pieces than the sets in the item list, omit the top current collector layer, before removing either Li-ion or cobalt oxide/graphite layers.

5. Sticker Templates

5.1. Larger classroom set (0.6 m high)

Cobalt Oxide Layer

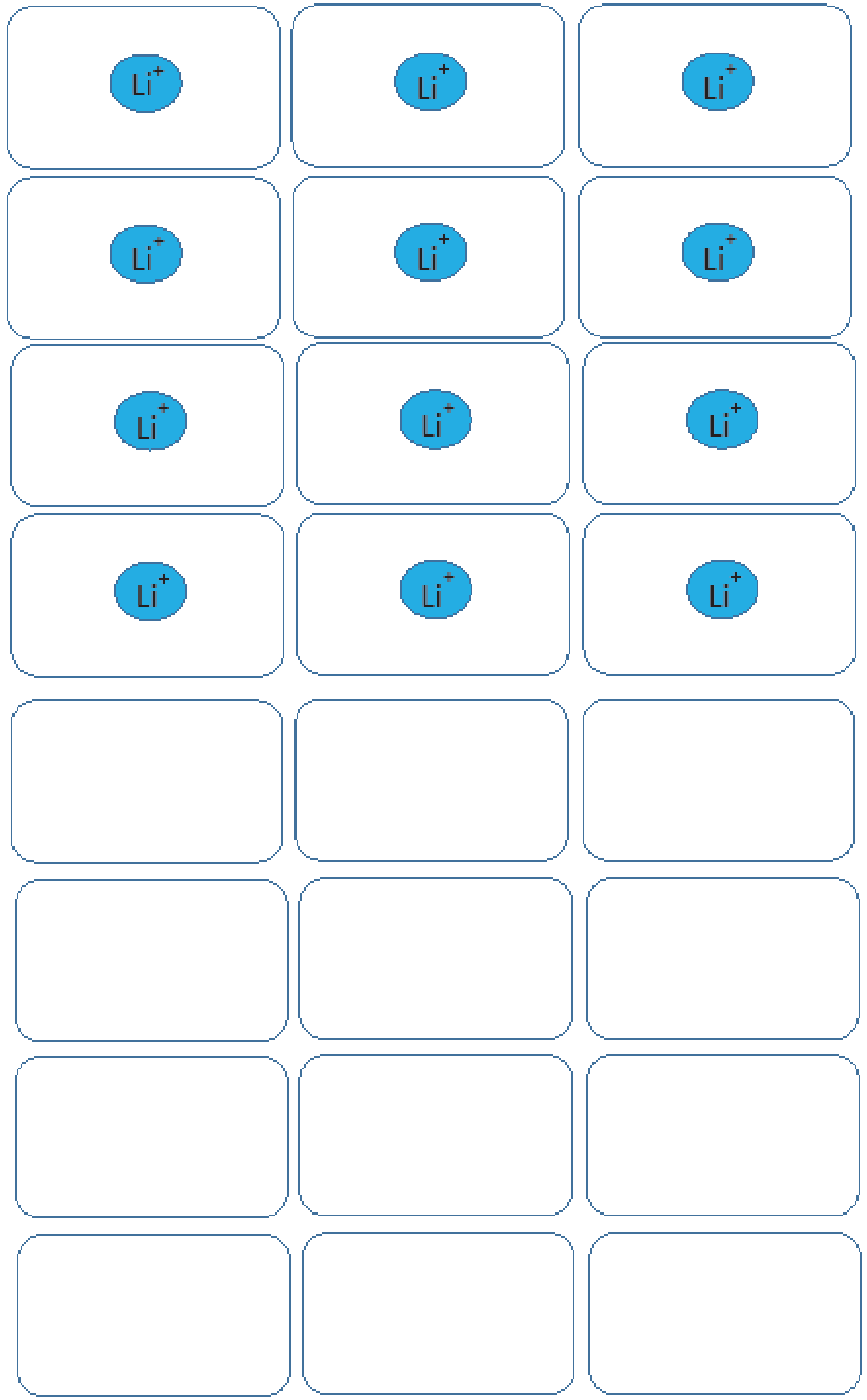
Cobalt Oxide Layer

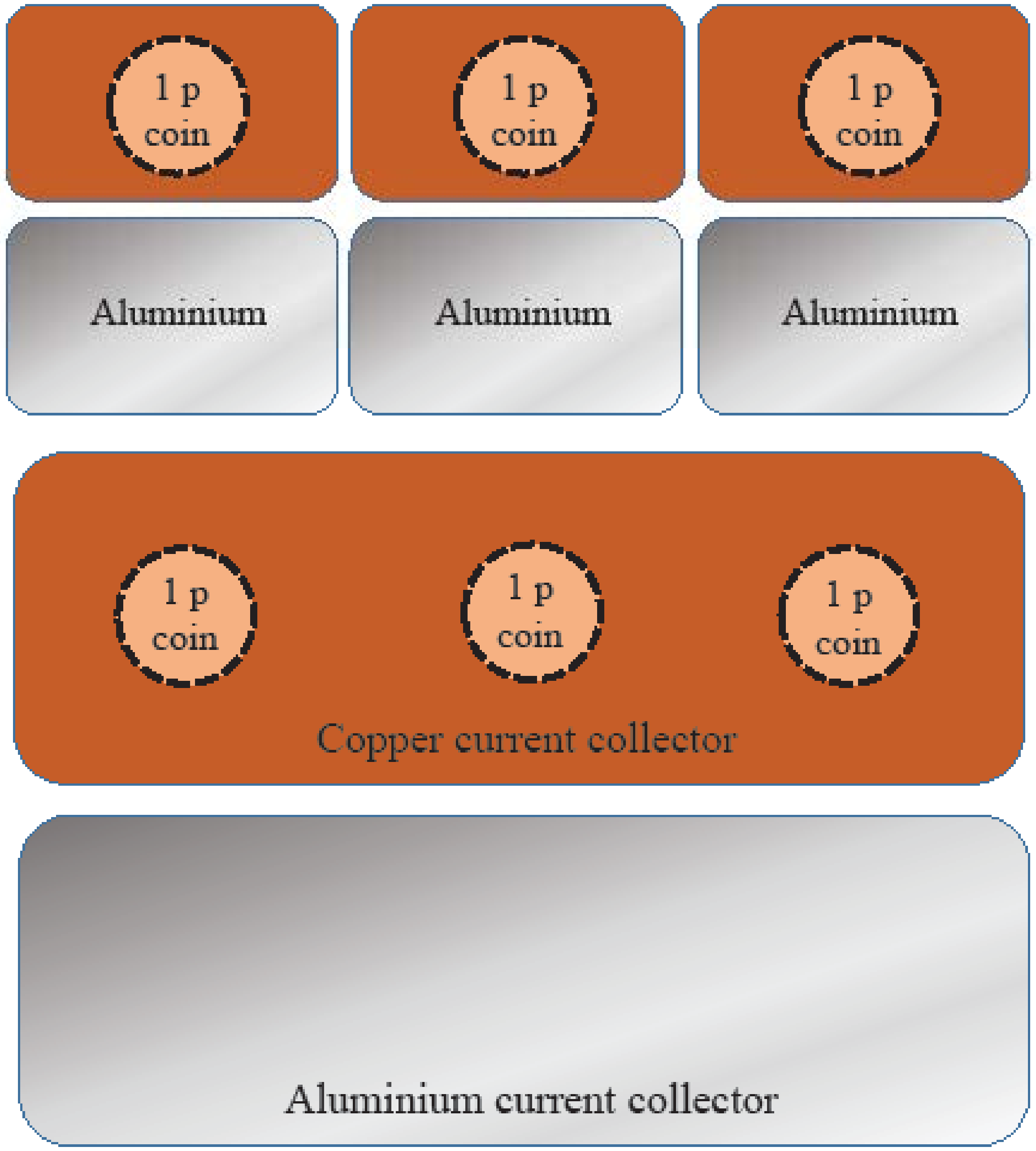
Cobalt Oxide Layer

Cobalt Oxide Layer

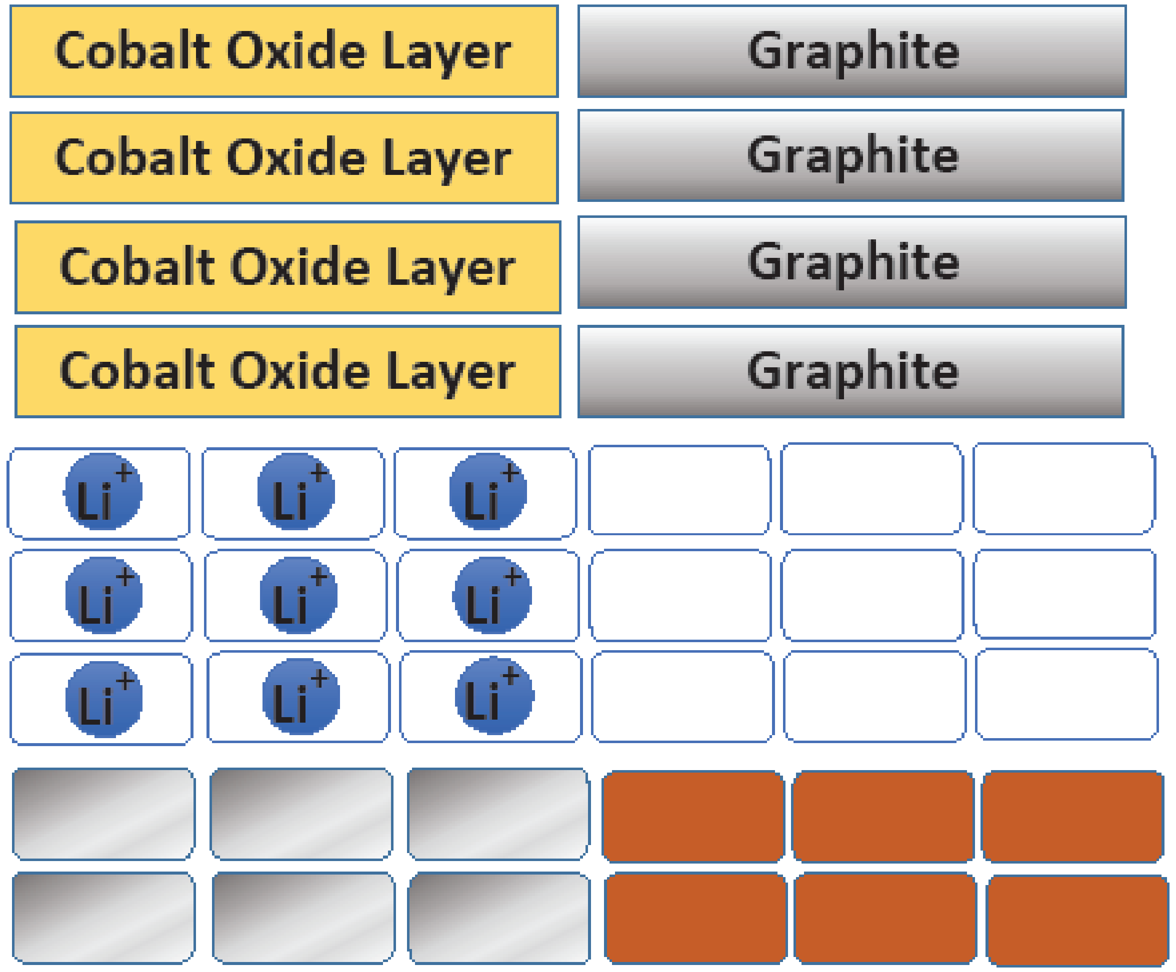
Cobalt Oxide Layer


Graphite
Graphite
Graphite
Graphite
Graphite

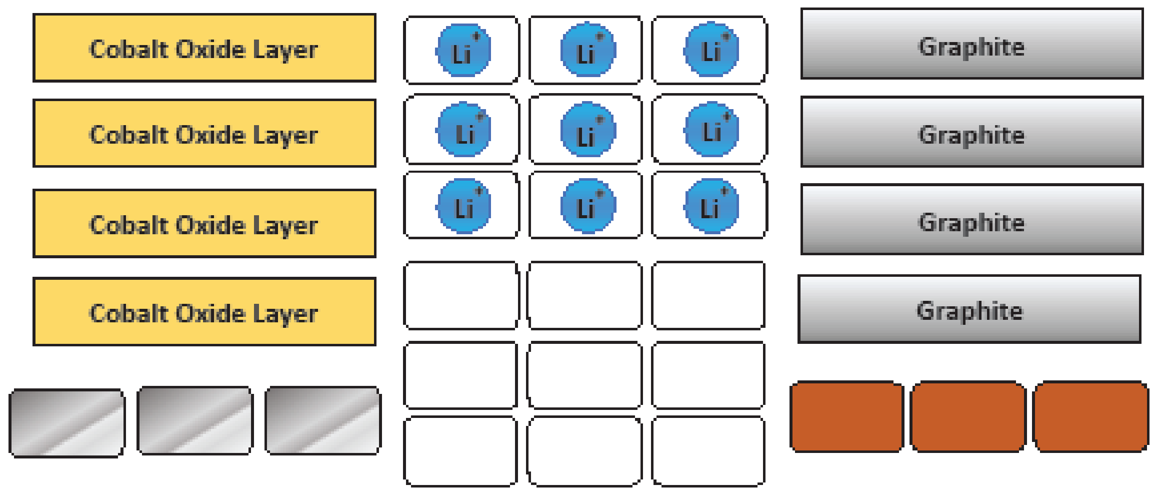

Li^+
Li^+
Li^+
Li^+
Li^+
Li^+
Li^+
Li^+
Li^+
Li^+
Li^+
Li^+



5.2. Small set (54 piece set - ca. 21 cm high)



5.3. Baby set (48 piece set, ca. 16 cm high)



Note: The 48 piece set is constructed in the same way as the 54 piece, however, there is no top current collector stickers.

6. UK Government Set Curriculum

In brief, this demonstration can be related to redox equation, reversibility, reaction favourability and electrochemical cells.

6.1. GCSE Chemistry Subject Content

Chemical symbols, formulae and equations

- use the names and symbols of common elements and compounds and the principle of conservation of mass to write formulae and balanced chemical equations and half equations
- use the formulae of common ions to deduce the formula of a compound and write balanced ionic equations

Redox reactions (reduction and oxidation)

- explain reduction and oxidation in terms of gain or loss of electrons, identifying which species are oxidised and which are reduced.

Structure and bonding of carbon

- explain the properties of diamond, graphite, fullerenes and graphene in terms oftheir structures and bonding.

Department for Education, Biology, Chemistry and Physics GCSE subject content June 2015, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/800342/GCSE_single_science_updated_May_2019.pdf (accessed June 2020).

6.2. GCE AS and A Level Chemistry Subject content

Redox

- oxidation states and their calculation
- oxidation and reduction as electron transfer, applied to reactions of s, p and d block elements
- electrode potentials and their applications

Inorganic chemistry and the periodic table

- the existence of more than one oxidation state for each element in it compounds

Department for Education, GCE AS and A level subject content for biology, chemistry, physics and psychology April 2014, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593849/Science_AS_and_level_formatted.pdf (accessed June 2020).

7. Examination Board Specification

7.1. AQA GCSE Chemistry (8462)

4.2.3.2 Graphite

In graphite, each carbon atom forms three covalent bonds with three other carbon atoms, forming layers of hexagonal rings which have no covalent bonds between the layers.

In graphite, one electron from each carbon atom is delocalised.
Students should be able to explain the properties of graphite in terms of its structure and bonding.
Students should know that graphite is similar to metals in that it has delocalised electrons.

4.4.1.4 Oxidation and reduction in terms of electrons (HT only)

Oxidation is the loss of electrons and reduction is the gain of electrons.
Student should be able to:
- write ionic equations for displacement reactions
- identify in a given reaction, symbol equation or half equation which species are oxidised and which are reduced.

4.5.2 Chemical cells and fuel cells (chemistry only)

4.5.2.1 Cells and batteries

- Cells contain chemicals which react to produce electricity.
- The voltage produced by a cell is dependent upon a number of factors including the type of electrode and electrolyte.
- A simple cell can be made by connecting two different metals in contact with an electrolyte.
- Batteries consist of two or more cells connected together in series to provide a greater voltage.
- In non-rechargeable cells and batteries the chemical reactions stop when one of the reactants has been used up. Alkaline batteries are non-rechargeable.
- Rechargeable cells and batteries can be recharged because the chemical reactions are reversed when an external electrical current is supplied.
- Students should be able to interpret data for relative reactivity of different metals and evaluate the use of cells.
- Students do not need to know details of cells and batteries other than those specified.

4.9.2 Carbon dioxide and methane as greenhouse gases
4.9.3 Common atmospheric pollutants and their sources

Can relate to why current research efforts are focusing on renewable energy generaion and storage.

4.10.1 Using the Earth's resources and obtaining potable water
4.10.1.4 Alternative methods of extracting metals (HT only)

- Bioleaching uses bacteria to produce leachate solutions thatcontain metal compounds.
- The metal compounds can be processed to obtain the metal. For example, copper can be obtained from solutions of copper compounds by displacement using scrap iron or by electrolysis.
- Students should be able to evaluate alternative biological methods of metal extraction, given appropriate information.

4.10.2.2 Ways of reducing the use of resources

The reduction in use, reuse and recycling of materials by end users reduces the use of limited resources, use of energy sources, waste and environmental impacts.

Relates to the Faraday Institution's ReLiB project:
Further reading: ReLiB project website and recent Nature review article on this topic.

AQA GCSE Chemistry (8462) October 2019, https://www.aqa.org.uk/subjects/science/gcse/chemistry-8462 (accessed June 2020).

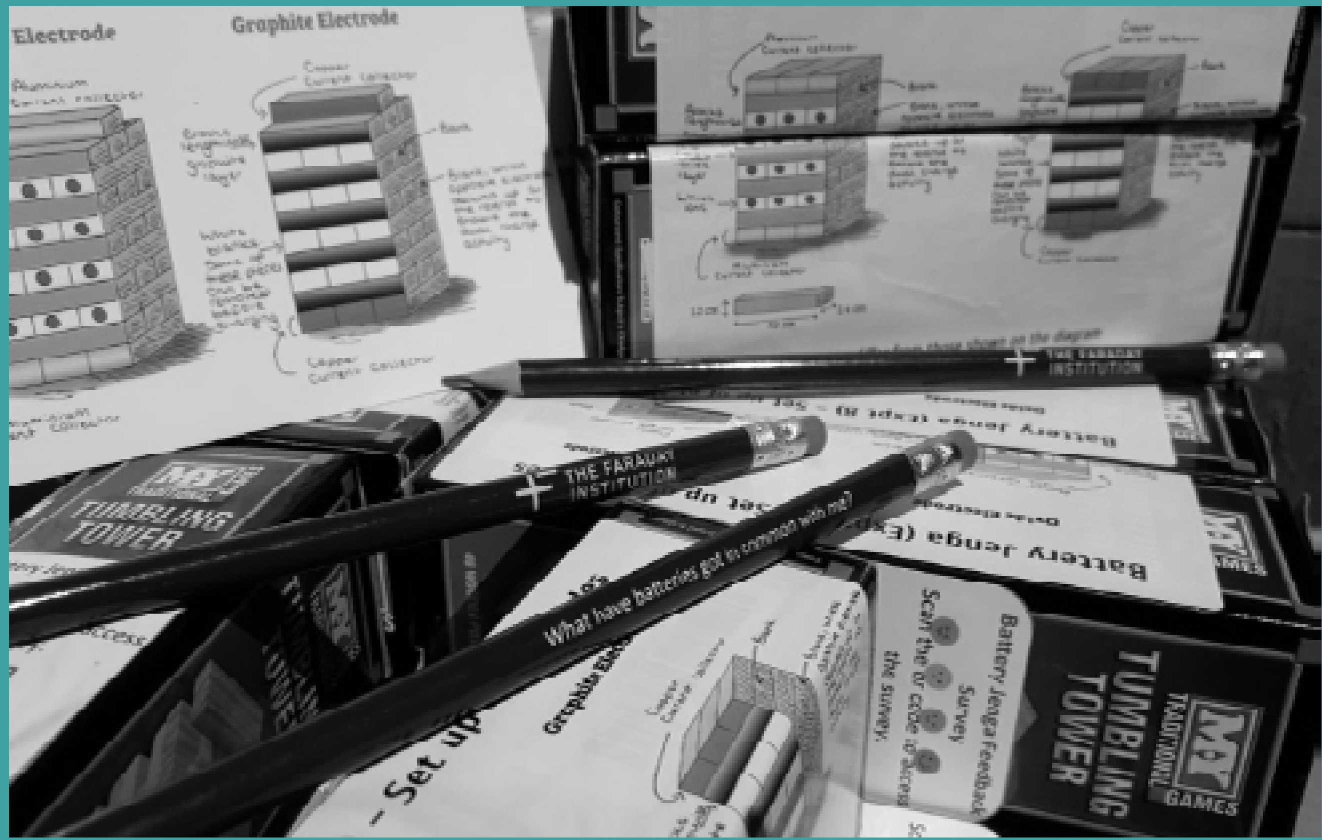
7.2. AQA AS and A-level Chemistry specification (7404, 7405)

Electrochemical cells can be used as a commercial source of electrical energy. The simplified electrode reactions in a lithium cell:

Positive electrode: $Li^+ + CoO_2 + e^- \longrightarrow Li^+[CoO_2]^-$
Negative electrode: $Li \longrightarrow Li^+ + e^-$

This equations are written for the direction of the battery discharging.

AQA AS and A-Level Chemistry AS (7404) A-level (7405) December 2015, AQA AS and A-level Chemistry, https://www.aqa.org.uk/subjects/science/as-and-a-level/chemistry-7404-7405 (accessed June 2020).



CoCoMAD 2020 (July 2020)


ThinkTank Museum (Aug. 2019)

8. Activity Sheet

8.1. Introduction

Lithium ion (Li-ion) batteries are a rechargeable-type of battery which have become a staple in modern-day life and are used in mobile phones, laptops and, in more recent times, electric vehicles. As these batteries are rechargeable they have to be charged, used (discharged) and then recharged. The majority of electrode materials currently used in Li-ion batteries have a layered structure, and so Jenga can be used to help demonstrate charging and discharging processes, in addition to exploring why batteries fail over time and why the rate of charge is important. The original Li-ion batteries used $LiCoO_2$ and graphite as the electrodes. In newer cells, some of the cobalt is typically replaced by nickel and manganese in order to reduce the cost (cobalt is a less abundant element).

8.2. What to investigate

8.2.1. Charging-Discharging

When batteries are charging, Li-ions move from the oxide electrode to the graphite electrode. The reverse process occurs on discharge.

- Have a go at charging your battery Jenga by removing the Li-ion blocks from the oxide electrode and inserting them between the layers of the graphite sheets on the graphite electrode (i.e. in place of the white blank blocks).

Charging

Discharging

Notes for Educators

The charging-discharging process will help students understand the shuffling motion of the Li-ions from one electrode to the other. The electronic process in the external circuit isn't shown in this set-up, but you could connect to board work of the half equations at play, in addition to understanding the layered structure of the systems.

8.2.2. Rate of Charge

Think about how long mobile phones take to charge - do you think electric cars take the same time to charge?

- Focusing on the oxide electrode, time yourself removing a Li-ion block every 10 seconds.
- How many Li-ions are you able to remove in the space of 30 seconds? How many could you remove in total, without collapsing the structure?
- Place all the Li-ion blocks back into the oxide electrode, so we have reset the structure.

Again, focusing on the oxide electrode, how many Li-ions can you remove in 30 seconds, if you remove the blocks every couple of seconds? (Don't worry if the structure collapses on this fast charge).

- On the different charging rates, what did you observe?
- If on the fast charge your structure collapses, what would that imply on the status of the health of the battery?

Notes for Educators

The main aim of this demonstration is to get students to think about the limitations in charging the batteries and how we need to be careful in terms of preserving battery lifetime, i.e. overcharging can result in structure collapse and degrade the cell (in severe cases battery fires could occur), so battery developers need to have a balance of a desire for rapid charging and preserving the battery lifetime.

8.2.3. Degradation

In the next demonstration we're going to think about the lifetime of the batteries.

- In the first demonstration where we showed charging and discharging (known as cycling our battery), did you find it tricky to remove the blocks? Did any of the electrodes collapse or were knocked quite easily?
- Cycle (charge and discharge) your battery Jenga set multiple times. Can it help you work out why batteries fail over time?

Notes for Educators

When considering degradation in batteries, making use of the natural movement of the Jenga blocks on removal of the Li-ions helps to visualize why over time batteries lose their ability to store electrical energy. This demonstration can be led by getting students to think about what happens to aged batteries and what happens to them at the end of their life. This area can be related to the Faraday Institution's ReLiB (recycling of Li-ion batteries) and be related to exam board material on making better use of Earth's resources.

9. Other Resources

Where can I learn more?

Article about this activity
https://pubs.acs.org/doi/abs/10.1021/acs.jchemed.0c00282

Battery Jenga Demonstration and Makers Guide Playlist
https://www.youtube.com/channel/UC7919XYrfY6pGWl21SO_RLA

Lithium Shuffle Video
(shows charging and discharging of Li-ion batteries)
https://www.youtube.com/watch?v=r1fXpQdqHgE

Lithium Shuffle Article
https://www.rsc.org/news-events/community/2020/mar/lithium-shuffle/

Faraday Institution CATMAT Project
https://catmatproject.com/

Faraday Institution NEXTRODE Project
https://faraday.ac.uk/research/lithium-ion/electrode-manufacturing/

Faraday Institution ReLiB Project
https://relib.org.uk/

Faraday Institution Outreach page
https://faraday.ac.uk/education-skills/stem-outreach/

Battery Technology (RSC website)
https://edu.rsc.org/feature/battery-power/2020096.article

Links accessed July 2020 and are correct at the time of publishing.

If you have any queries or feedback, please email or contact us via Twitter :

Elizabeth Driscoll
ehd345@bham.ac.uk
@EHDriscoll

Prof. Peter Slater
P.R.Slater@bham.ac.uk
@prslaterchem

Show us your creations and the demonstrations in use with the #BatteryJenga on Twitter.