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Experimentell kemi i Skellefteå 2024

Greenhouse Academy

Agenda

August 15th, Campus Skellefteå, 9 am – 12 pm

09.00 – 09.30	Welcome and Introduction to NV
09.30 – 09.45	Introduction to NV Ett Academy
09.45 – 10.15	Li-ion battery manufacturing
10.30 – 11.30	Practical activities
11.30 – 12.00	Q & A





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Li-ion Battery Manufacturing - Mix Martial Arts of Science

Greenhouse Academy

Motivation & Objective

Motivation

- Spark the interest in science
- Spread understanding of (Li-ion) batteries
- Spread knowledge of Li-ion battery manufacturing

Objectives

- Deliver talking points on (Li-ion) battery basics
- Provide ideas for practical class activities



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Introduction to Li-ion battery (manufacturing)



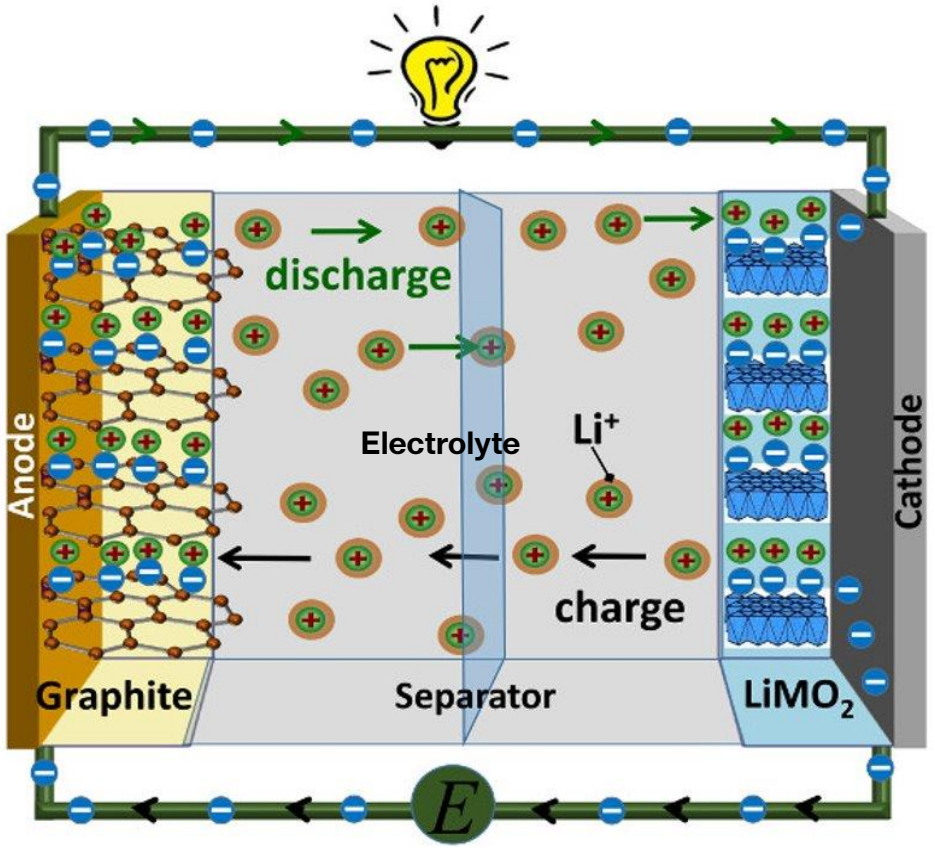
What is a Li-ion battery?

A Li-ion battery is a rechargeable battery (secondary battery) which uses the reversible transfer of Li-ions between anode and cathode to store energy by **intercalation** chemistry.

<u>Conventional cell:</u>

- Anode = graphite
- Electrolyte = organic solvent + Li-salt
- Separator = polymer membrane
- Cathode = Lithium metal oxide (such as $LiCoO_2$)

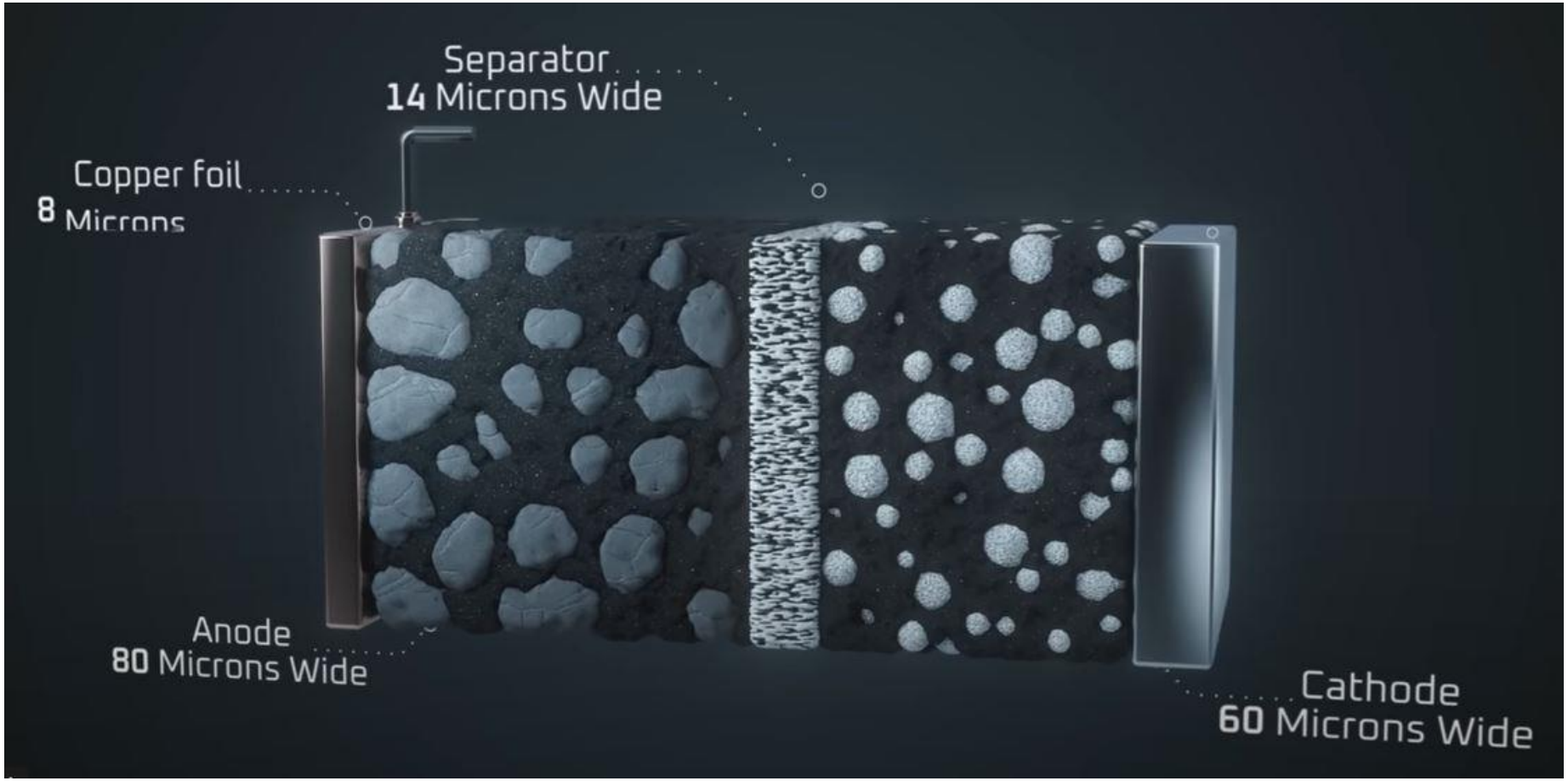
Anode:	$LiC_6 \rightleftharpoons C_6 + Li^+ + e^-$	-3.0 V vs. SHE
Cathode:	$CoO_2 + Li^+ + e^- \rightleftharpoons LiCoO_2$	1.0 V vs. SHE
Full cell:	$LiC_6 + CoO_2 \rightleftharpoons C_6 + LiCoO_2$	



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Real design of a Li-ion battery

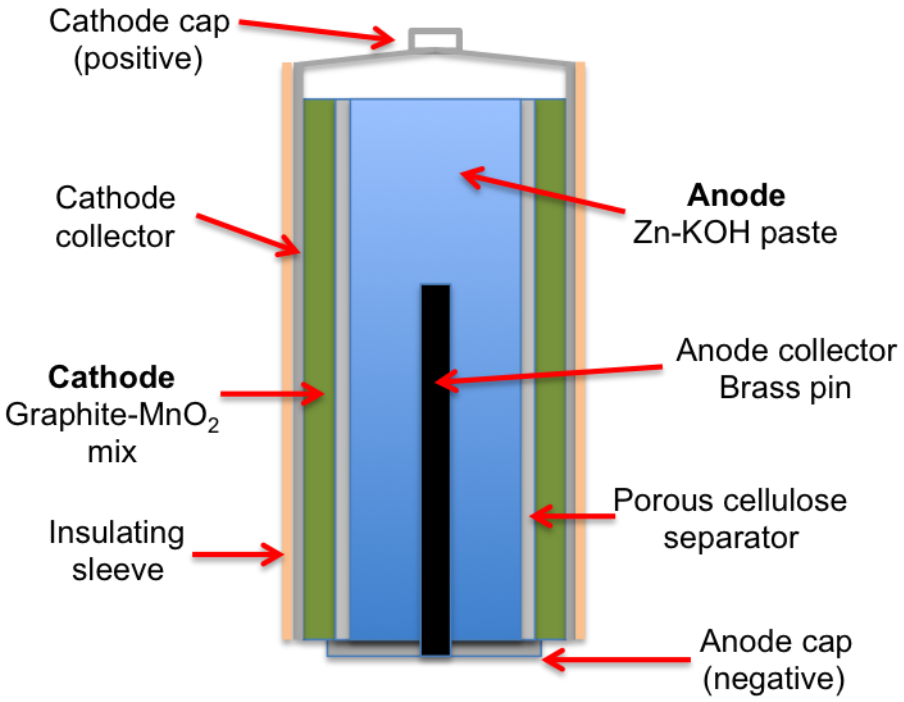


From: YouTube - How a Li-ion battery actually works

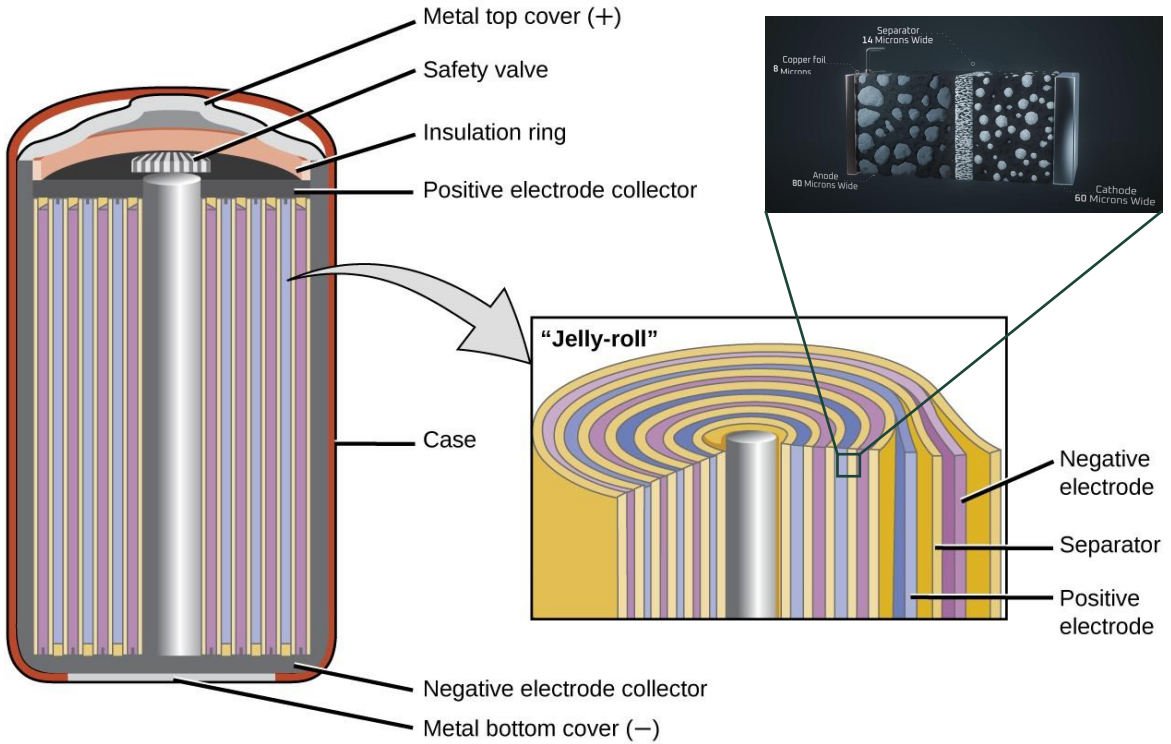
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Comparison to other batteries

Alkaline battery



Li-ion battery (cylindrical)

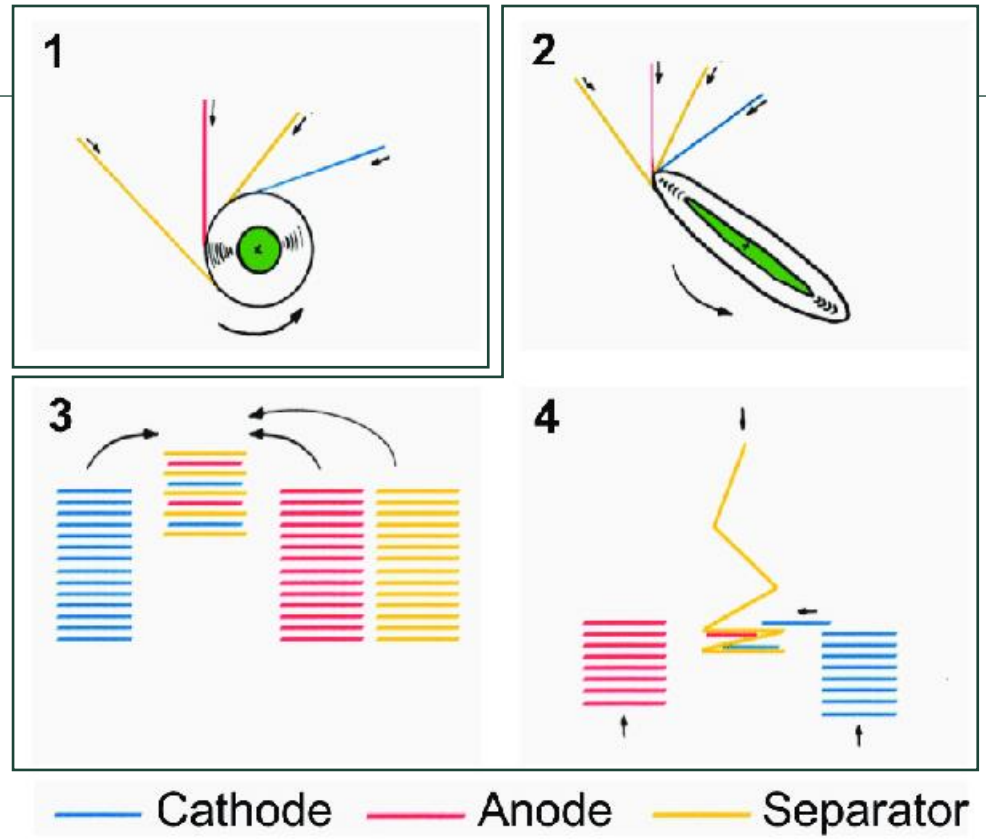


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Li-ion battery form factors



Cylindrical



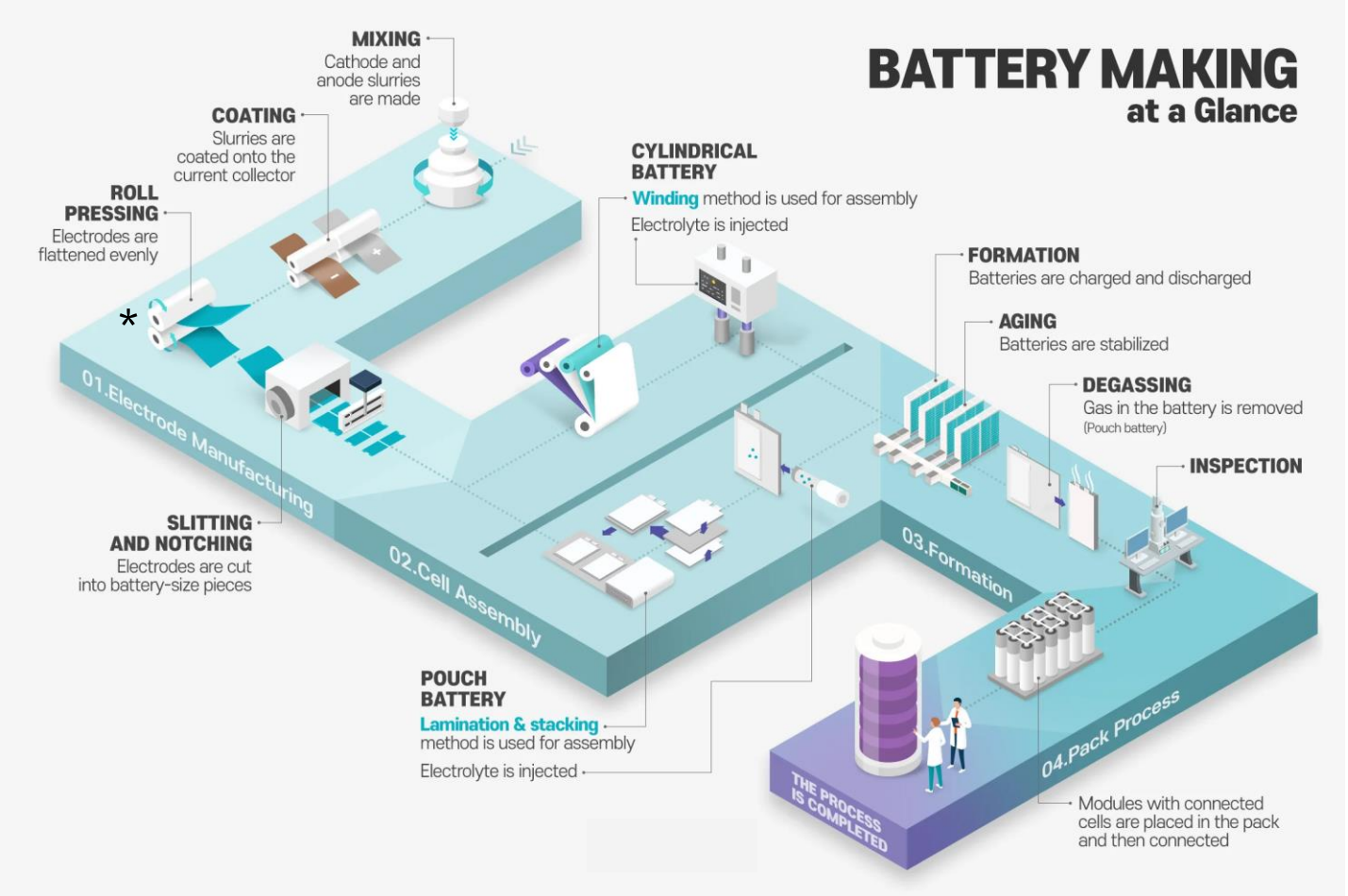


Prismatic

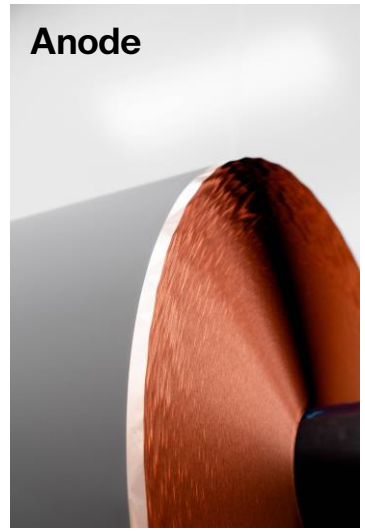
(1) round winding; (2) prismatic winding, (3) stacking, (4) z-folding

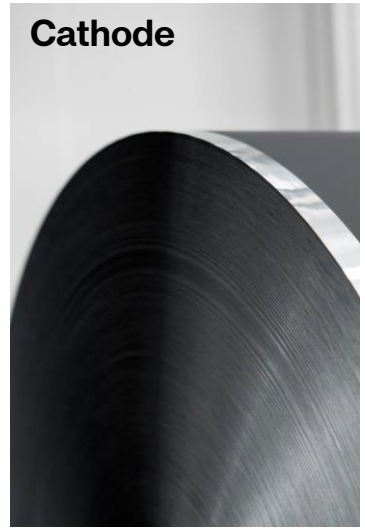
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Li-ion battery manufacturing



More material: [Li-ion battery cell production process by PEM, RWTH Aachen]





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Talking points on (Li-ion) battery (basics)



What is a Li-ion battery?

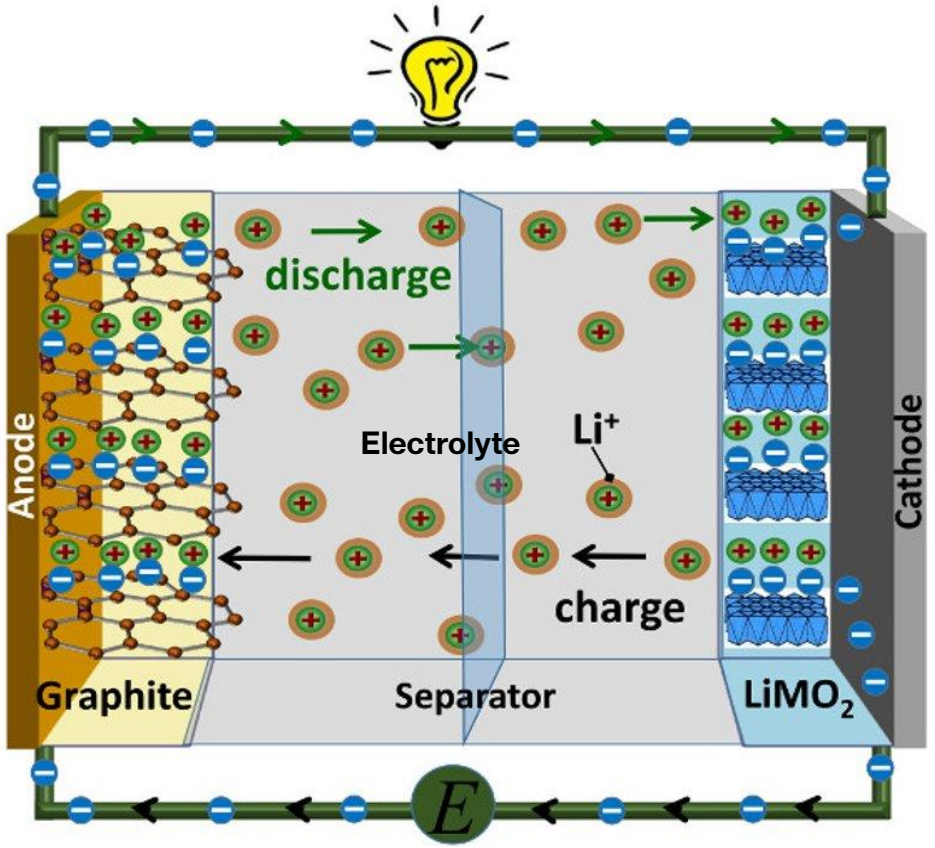
1 e^- per 1 Li^+ → **Amount of material = Amount of energy**

A Li-ion battery is a rechargeable battery (secondary battery) which uses the reversible transfer of Li-ions between anode and cathode to store energy by **intercalation** chemistry.

Conventional cell:

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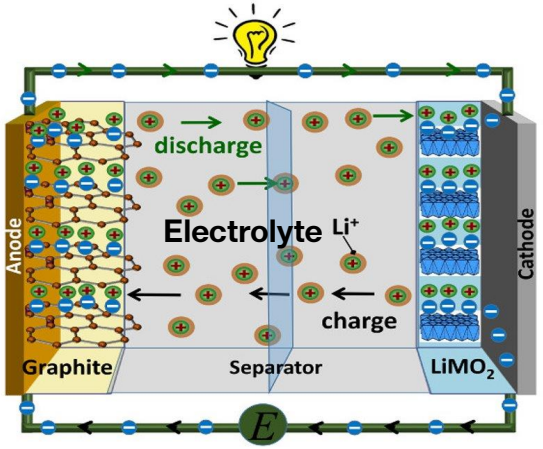


Comparison to other materials (metals) // aqueous electrochemistry

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What is a Li-ion battery?

Battery / Parking garage analogy





Anode

Discharging

Charging



Cathode

>2 parking spots per car
(Cars = Li-ions)

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Battery material specific capacity - Q_{spec}

How many (Li-ions) electrons can be delivered **at best**?



Task: Count the maximum amount of charge per mass unit.

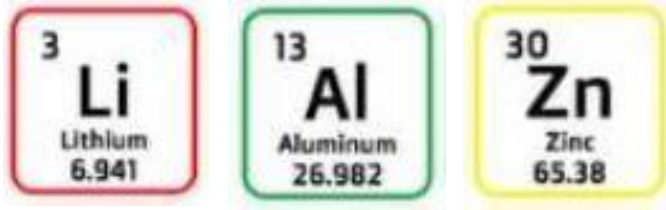
→ Faraday's laws

$$Q_{spec} = \frac{Q}{M} = \frac{n \cdot F}{M}$$

Q_{spec}: Specific capacity [Ah/g]
Q: Molar capacity [Ah/mol]
M: Molar weight [g/mol]
n: Electrons per formal unit
F: Faraday's constant (=26.8 Ah/mol)

Exercises:

- Calculate the specific capacity of Lithium (Li/Li^+)
- Calculate the specific capacity of Aluminum (Al/Al^{3+})
- Calculate the capacity of 2 g of Zinc (Zn/Zn^{2+})

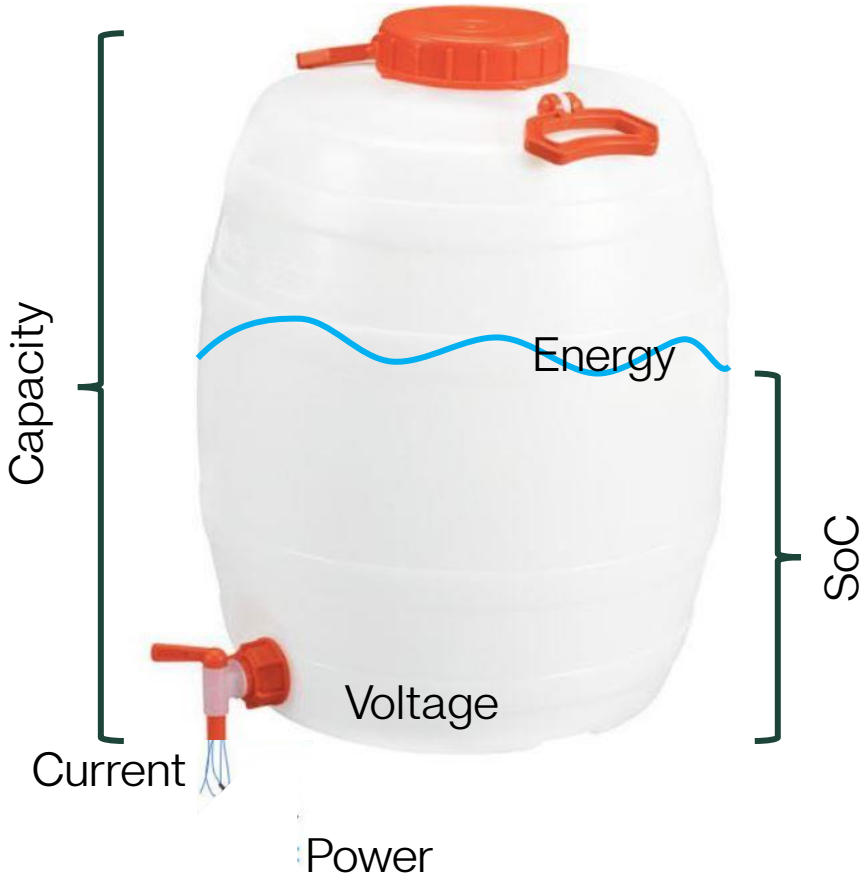


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How can we understand battery properties? Analogies!

Battery / Bucket analogy



A battery is in many ways like a bucket of water:

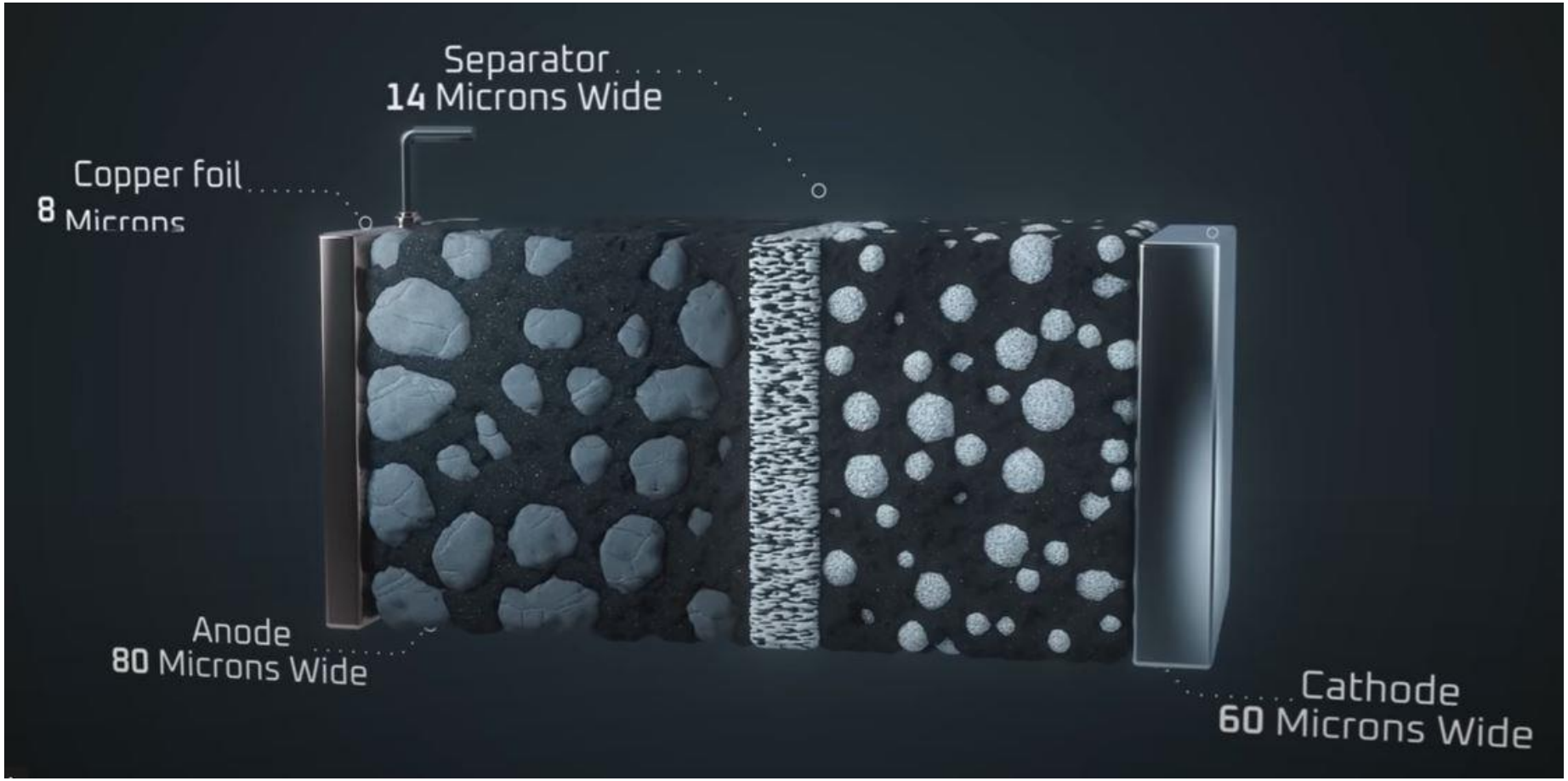
Name	Abbrev.	Unit	Unit symbol	Bucket analogy
Anode Potential	OCP / ϕ	Volt	V	Filling level
Cathode Potential	OCP / ϕ	Volt	V	Outlet level
Voltage	(OC)V	Volt	V	Water pressure in bucket
Current	I	Amp	A	Flow rate of water
Capacity	Q	Amp hour	Ah	Volume of bucket
State of Charge	SoC	Percent	%	Percentage full
Energy	E	Watt hour	Wh	Filling level-weighted amount of water
Internal Resistance	R	Ohm	Ω	Size of the Pipe
Power	P	Watt	W	Force of water exiting

Internal

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Real design of a Li-ion battery

How do they really look like?



From: YouTube - How a Li-ion battery actually works

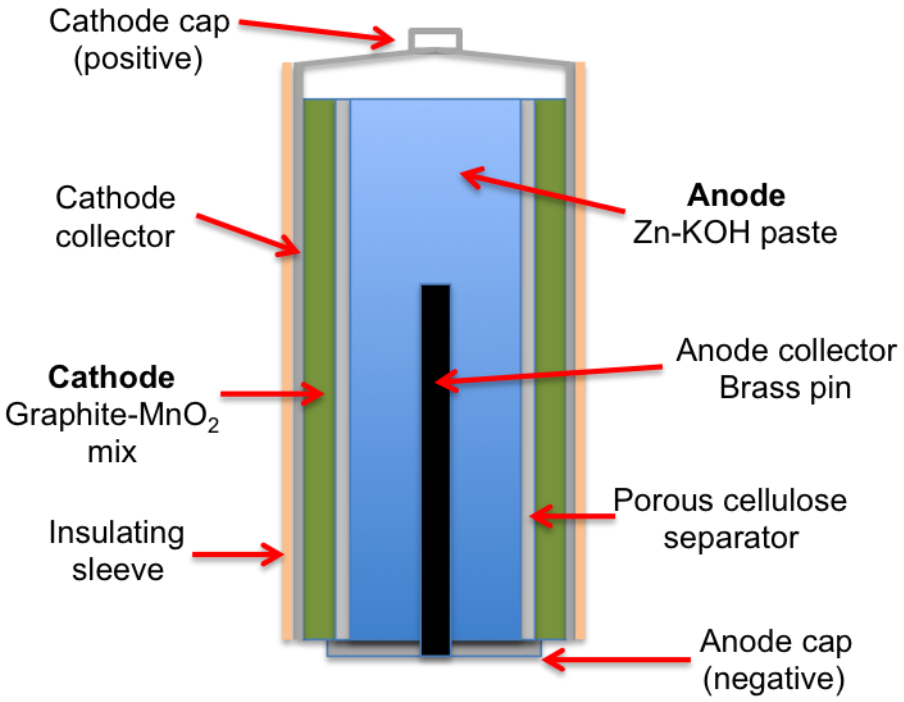
Internal

Comparison to other batteries

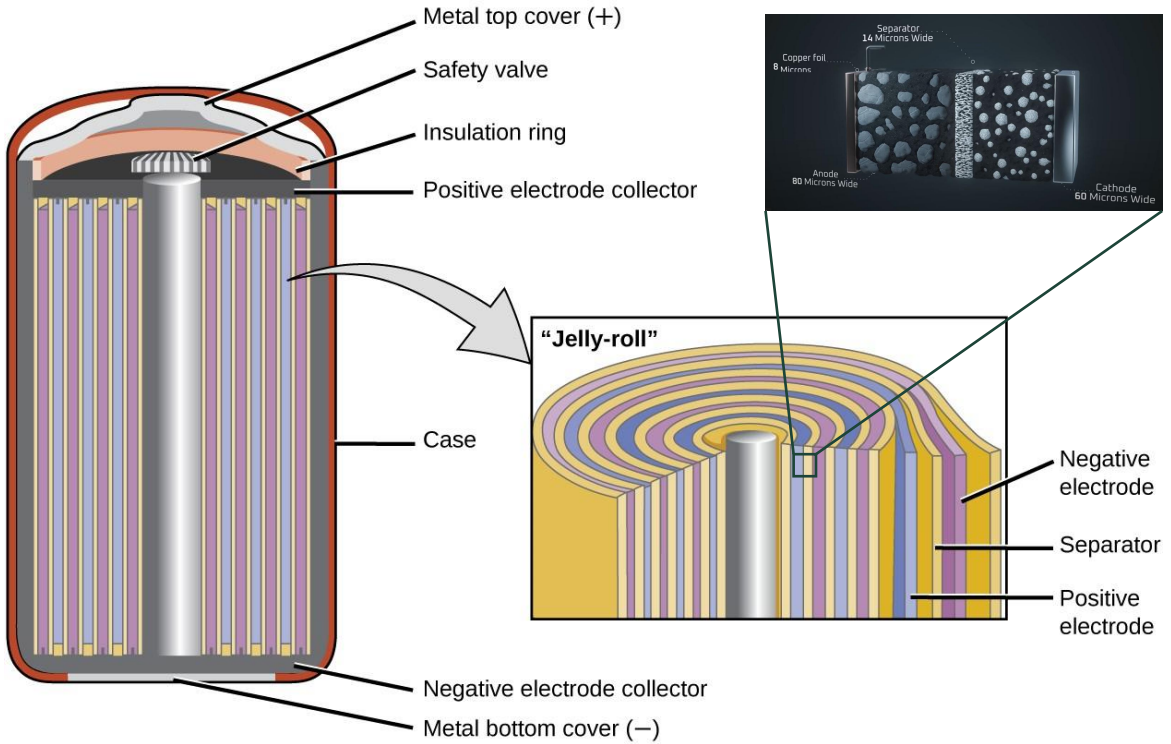
How do they compare to other batteries?

→ Large surface area required!

Alkaline battery



Li-ion battery (cylindrical)



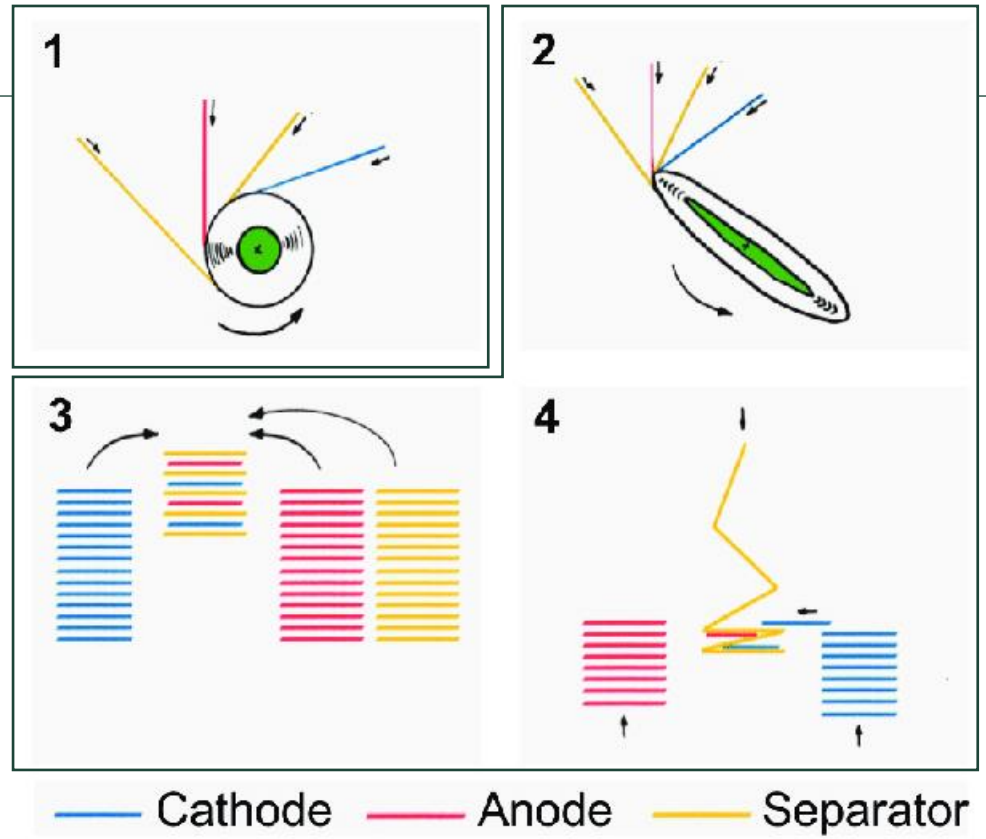
Internal

Li-ion battery form factors

How are they manufactured?



Cylindrical





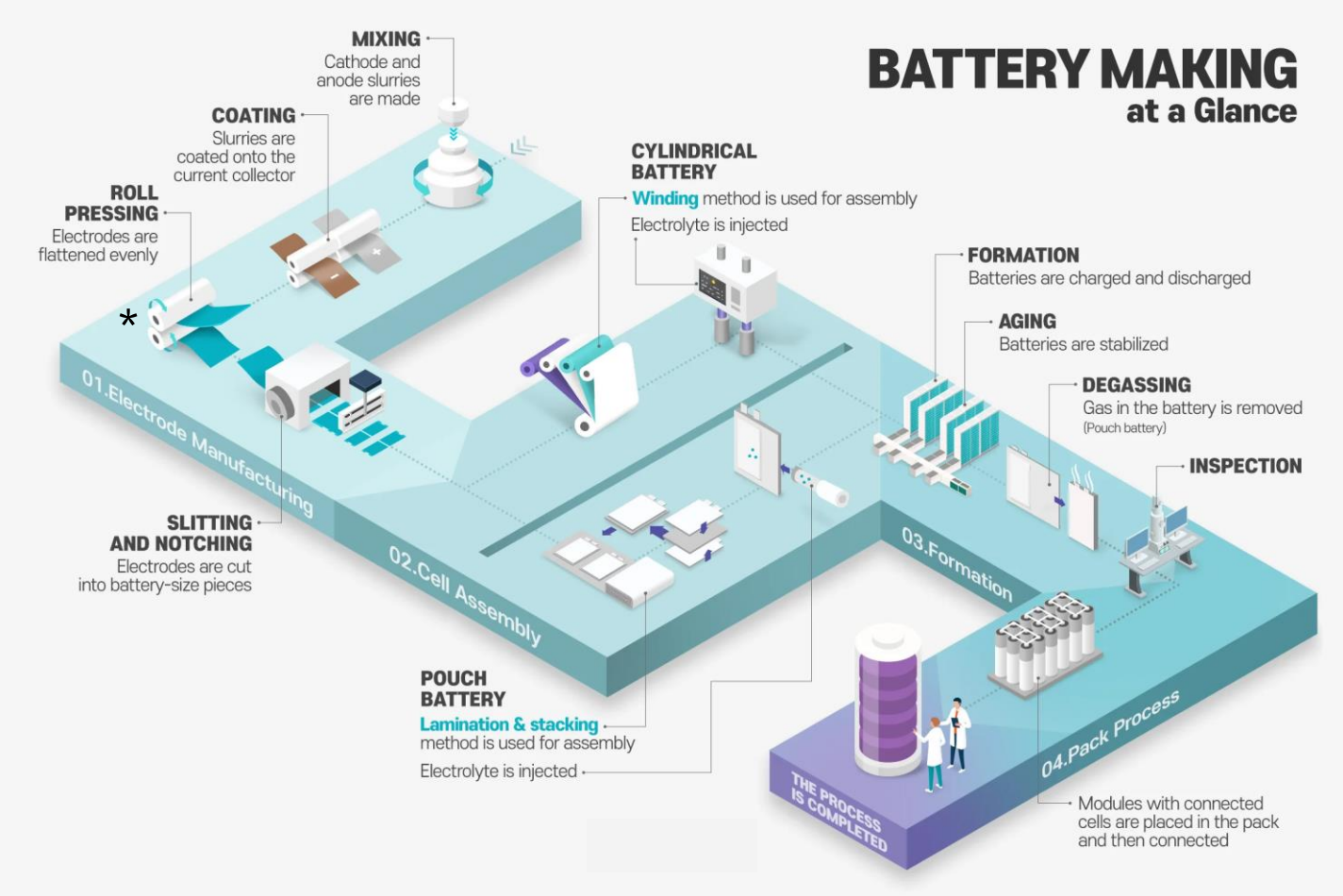
Prismatic

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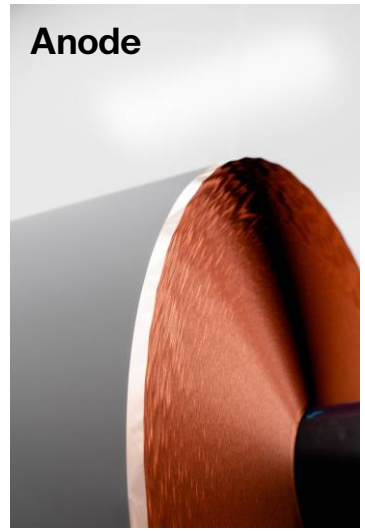
Internal

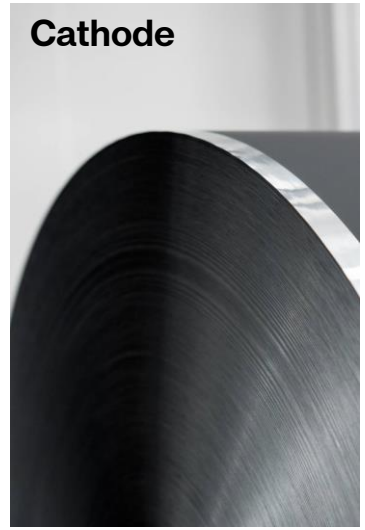
Li-ion battery manufacturing

How are they manufactured?



More material: [Li-ion battery cell production process by PEM, RWTH Aachen]





Internal

Practical class activities



(1) The “Penny Battery”

Battery basics orientated exercise



<u>Potential student experiment:</u>

Build a penny battery to light a LED.

Teacher to prepare larger stack to power a “device”

Measure voltage and current:

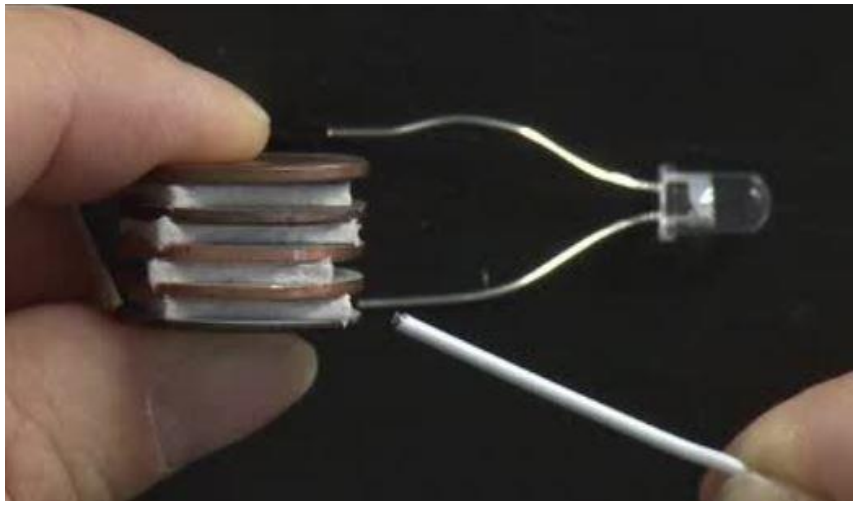
→ **Derive correlation between surface area/current/power**

(US pennies potentially replaced by zinc & copper pieces)

Internal

The “Penny Battery”

1. Cut your felt into circles, each about the size of a penny. Soak the pieces in salt-and-vinegar solution. Once the pieces are thoroughly wet, take them out and place them on a paper towel so they are still damp, but **not dripping**.



2. Use sandpaper to remove the copper from ONE side of (n-1) pennies. Leave one penny intact. Sand until you see shiny silver color covering the entire face of the coin.

3. Take one of your sanded pennies with the silver side facing up and place a damp piece of felt on it. Then stack another sanded penny (again, silver side facing up) on top of this. Take your next piece of felt and place it on top and continue stacking pennies and felt on top of each other to make a neat pile. Finally, place the unsanded penny at the very top.

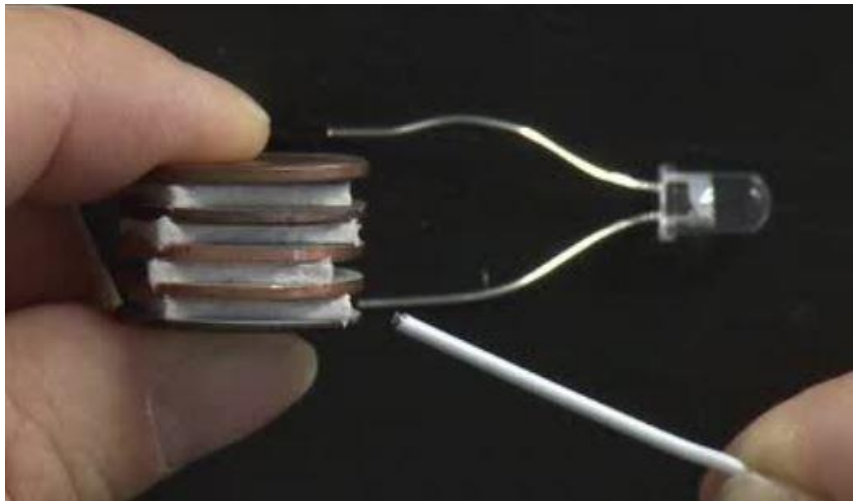
4. Test your battery by connecting a LED. (Measure the OCV using a multimeter)

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The “Penny Battery”

Potential talking points:

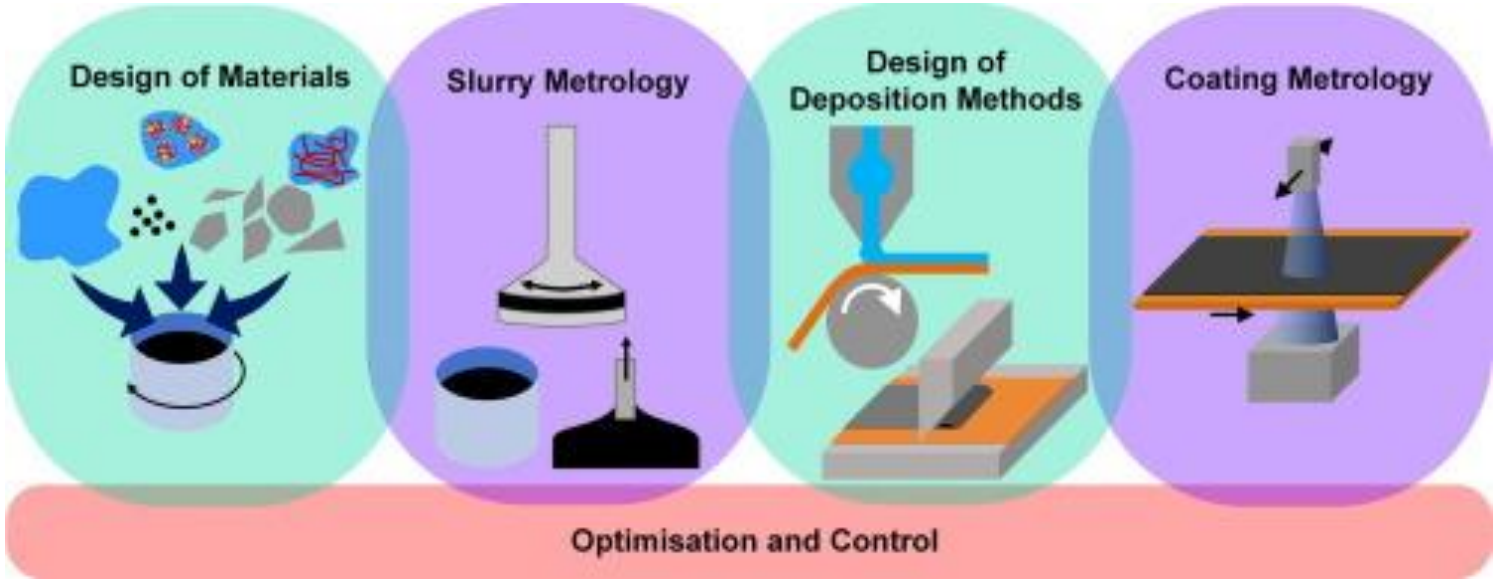
- Elements of a battery (electrodes, electrolyte, separator)
- Cell reactions (here: Zn; H_2)
- Electrochemical series: different elements → different OCV
- Nernst equation: calculate OCP/ cell voltage
- Series connection of cells = increase voltage
- Correlation electrode area and current
- Electrical power: $P = U \cdot I$
- Difference between OCV and operating voltage



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(2) Electrode manufacturing

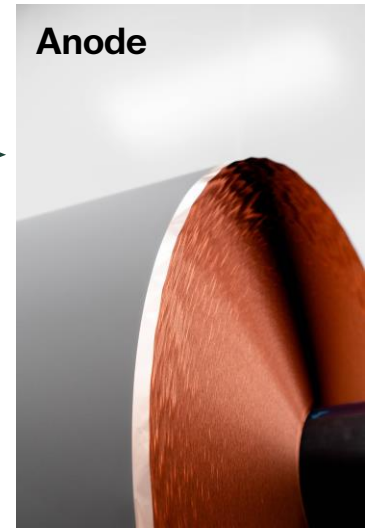


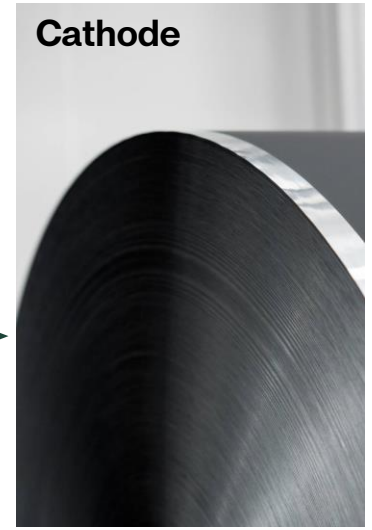
Mixing

- **Viscosity**
- Adsorption

Coating

- **Viscosity**
- Adhesion





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(2.1) Viscosity



<u>Potential student experiment:</u>

Dissolve various amounts of CMC in water.
Measure viscosity in a cylinder.

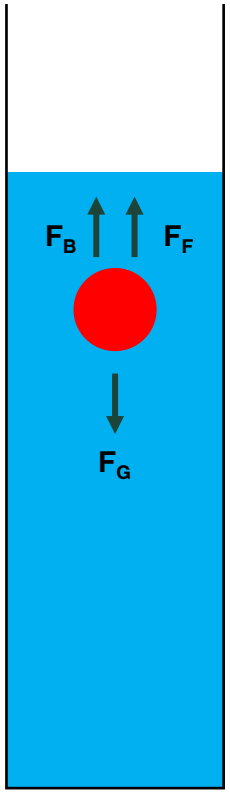
Possibly calculate viscosity from falling time of sphere. (Determine density of liquid)

→ **Derive the understanding of viscosity**

Substance	Viscosity [mPa s]
Benzene	0.604
Water	1.0016
Mercury	1.526
Whole milk	2.12
Dark beer	2.53
Olive oil	56.2
Honey	≈ 2000–10000
Ketchup	≈ 5000–20000
Peanut butter	≈ 10^4–10^6
Pitch	2.3×10^{11}

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(2.1) Viscosity



Gravity

$F_G = m \cdot g$

Bouyancy

$F_B = \varphi_{liq} \cdot V_{Sphere} \cdot g$

Friction (Stokes)

$F_F = 6 \cdot \pi \cdot r_{Sphere} \cdot \eta \cdot v$

$$F_G = F_B + F_F$$

$$\eta = \frac{m \cdot g - \varphi_{liq} \cdot V_{Sphere} \cdot g}{6 \cdot \pi \cdot rSphere \cdot v}$$

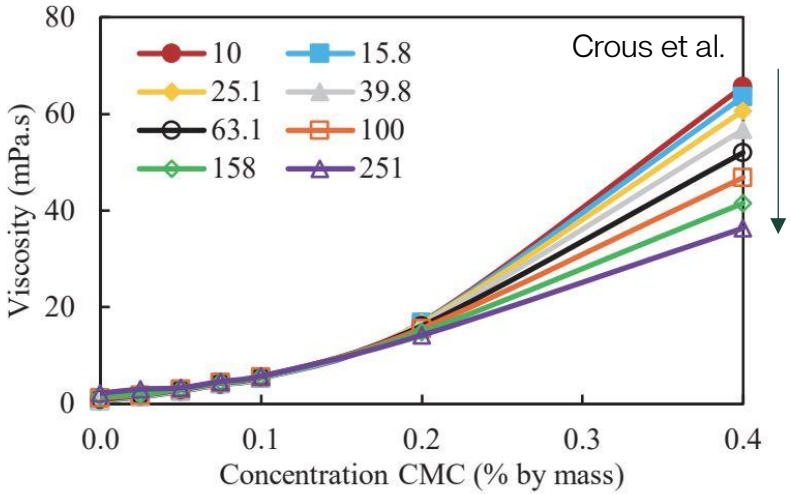


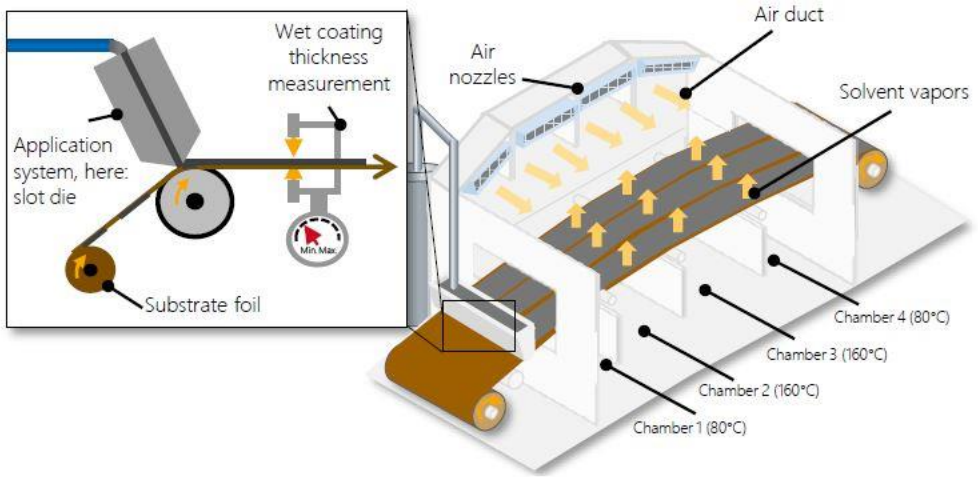
Fig. 2: Viscosity of CMC-water mixtures at different concentrations at various shear rates.

Shear thinning behavior

Possible extension: Dry solution to recover solid.
→ Correspondence to 2.2.

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(2.2) Coating



Battery manufacturing details

Use 2 different wall paint colors to coat metal foil by doctor blading. (Copper foil too expensive?)

Build doctor blade.

Dilute wall paint to simulate different slurry viscosity.

Which paint provides best coating result?

Dry coated electrodes for follow-up experiment.

→ **Build correlation between viscosity and coating properties.**

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(3) Recycling





Black mass:
Active material and residual mixture after crushing and sorting of depleted Li-ion batteries

Battery recycling via **hydrometallurgy** involves dissolving metals from the so called 'black mass' in a solution containing sulfuric acid under optimized conditions. Impurities such as copper, iron, and aluminium are then removed using techniques including precipitation, solvent extraction and ionic exchange.

Teacher experiment:

- Prepare a solution of metal ions (e.g., Al & Ni, pH = 0)
- Add/titrate NaOH solution
- Filter precipitate
- Continue adding NaOH to separate metal ions

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Q & A session



Resources

Experimental description

https://www.pem.rwth-aachen.de/cms/pem/der-lehrstuhl/~hwpp/aktuelle-downloads/?lidx=1

https://www.youtube.com/watch?v=4-1psMHSpKs&t=908s

https://edu.rsc.org/resources/lithium-ion-cells-worksheet-16-18-years/4016604.article

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