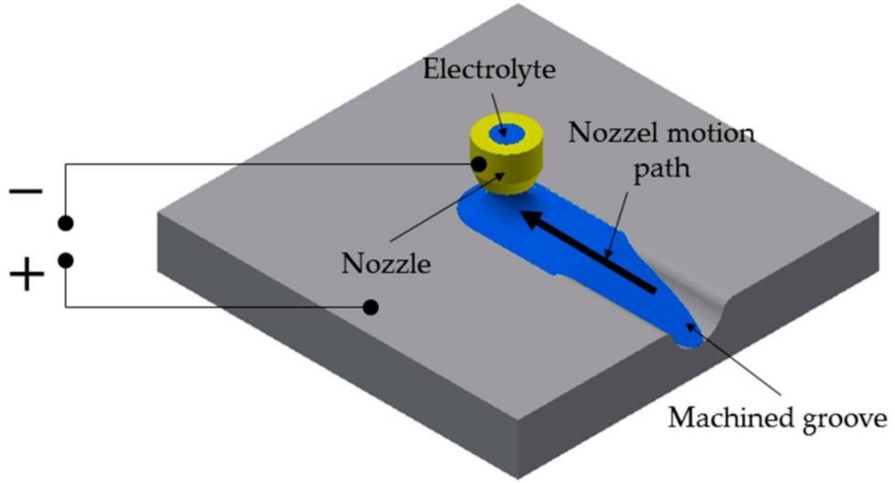
Electrochemical Machining (ECM)

Nimonic alloys (nickel with Al, Ti, and Mo)

Used in the aircraft industry resist deformation even at high temperatures and are exceedingly difficult to machine by the normal cutting process

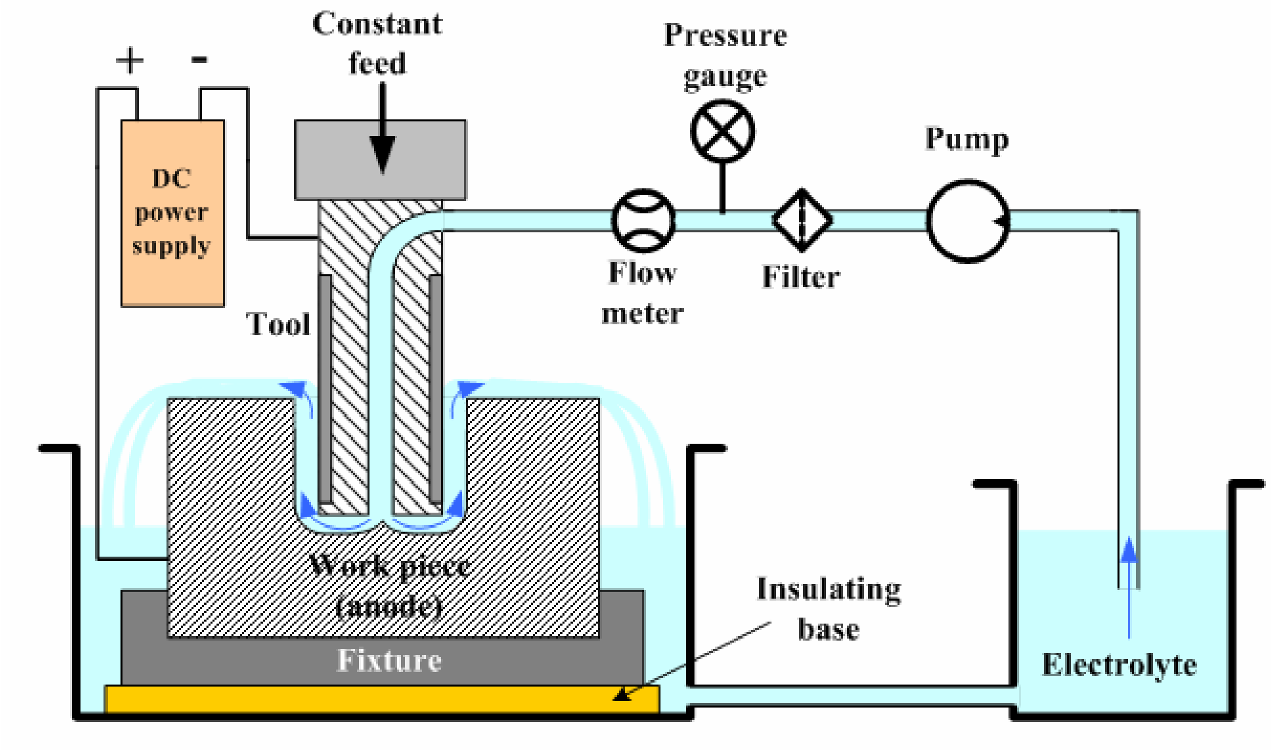


Jet ECM

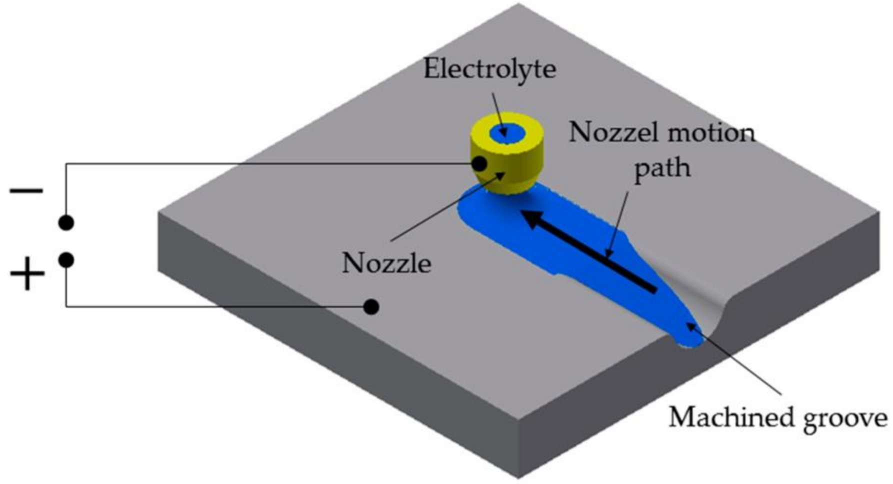
Micromachines **2019**, *10*(4), 261

In ECM, hard, tough metals can be dissolved as readily as soft metals. **5×10^{-3} mm/min** can be removed at a current density of **0.3 amp/cm²**.

Electrochemical Machining (ECM)



The components of ECM

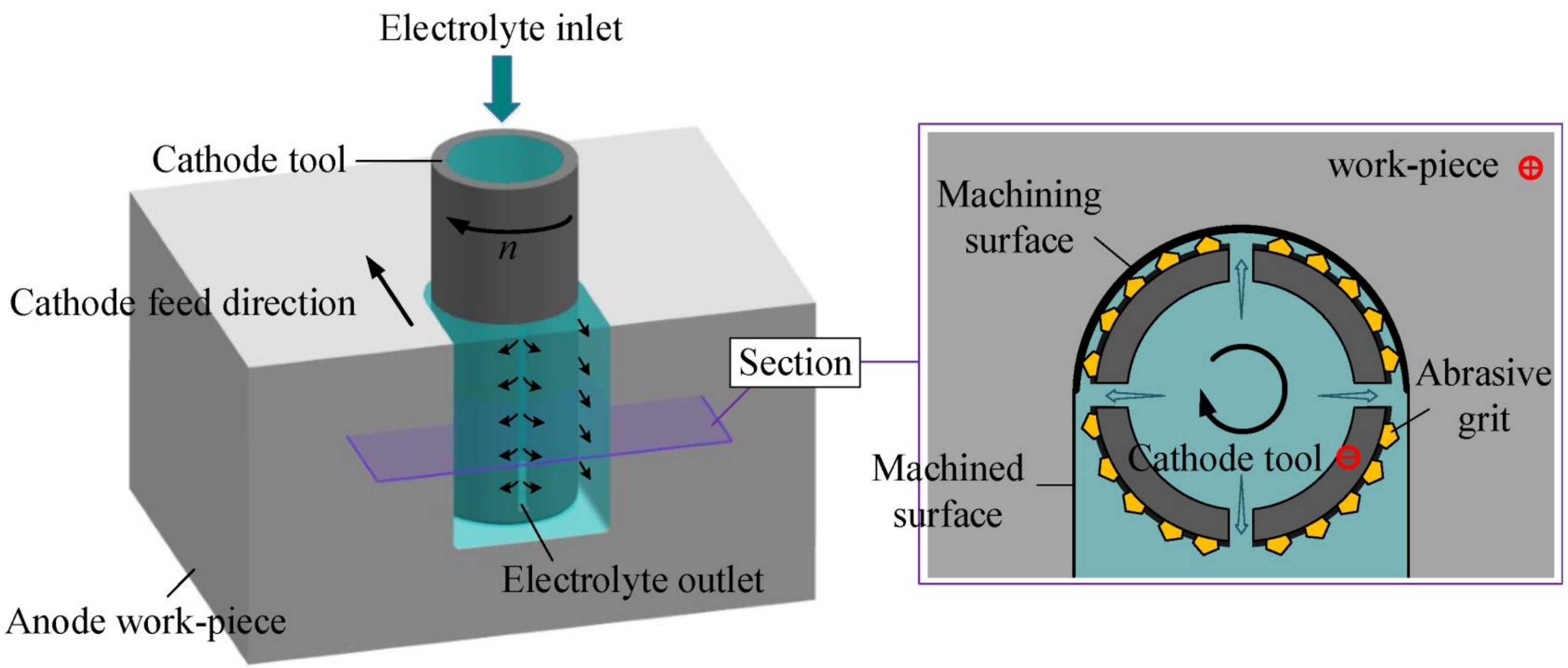


Jet ECM

Micromachines **2019**, *10*(4), 261

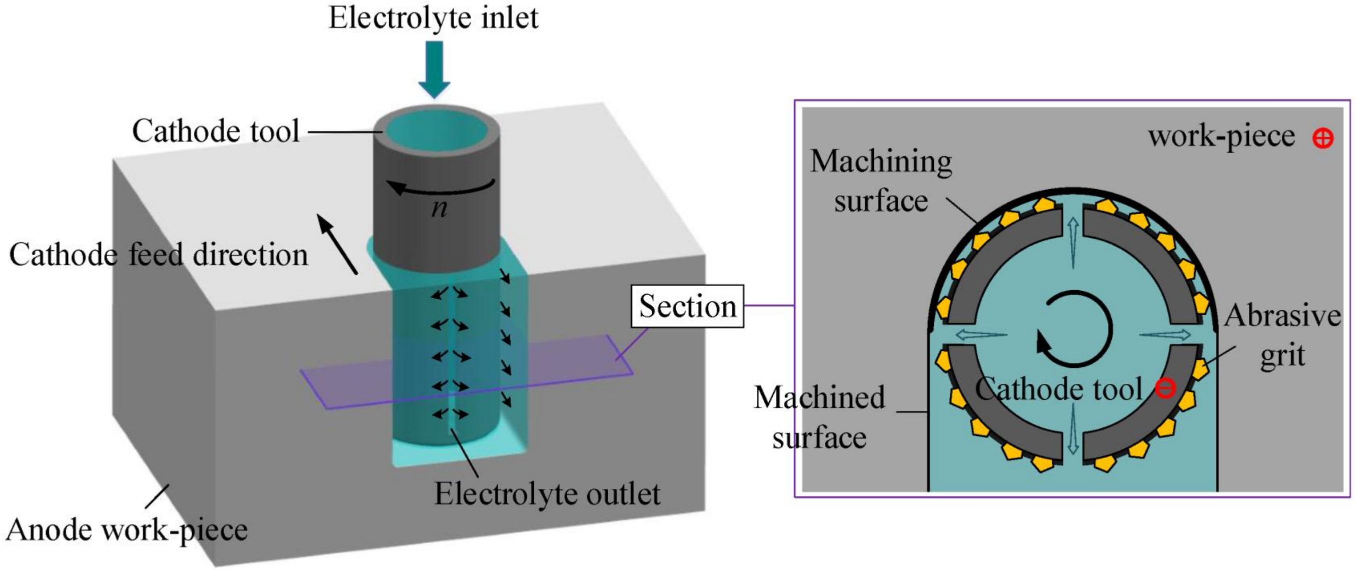
ECM: Cathode

- The cathode is a tool shaped to conform to the desired cut in the workpiece.
- The tool is usually made from copper, steel, or alloy and insulated on the sides to give directed current lines.



ECM: Electrolyte

- The purpose of the electrolyte is to provide a conducting medium, and at the same time, it must not corrode the cathode tool.
- The cheapest material commonly used is sodium chloride (NaCl) at about 30% by weight.
- Other electrolytes such as $Na_2Cr_2O_7$, $NaNO_3$, and $NaClO_3$ at 50–250 g/L have also been used, but the choice is limited primarily by cost.



EMF (Electromotive Force)

EMF is the work done per unit charge in moving a positive charge from the negative electrode to the positive electrode through the cell's internal circuit.

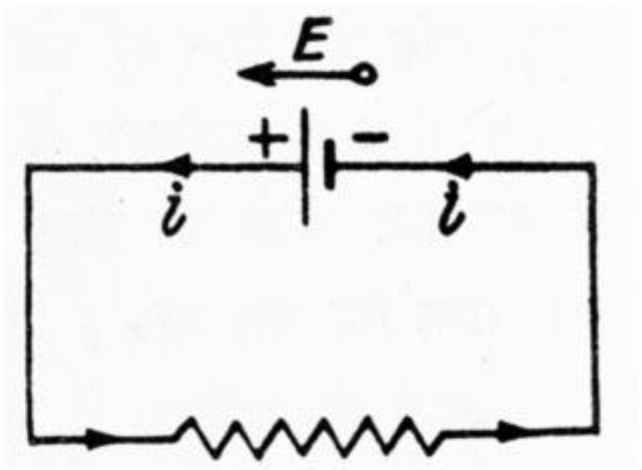
Electromotive force (EMF) of a Cell

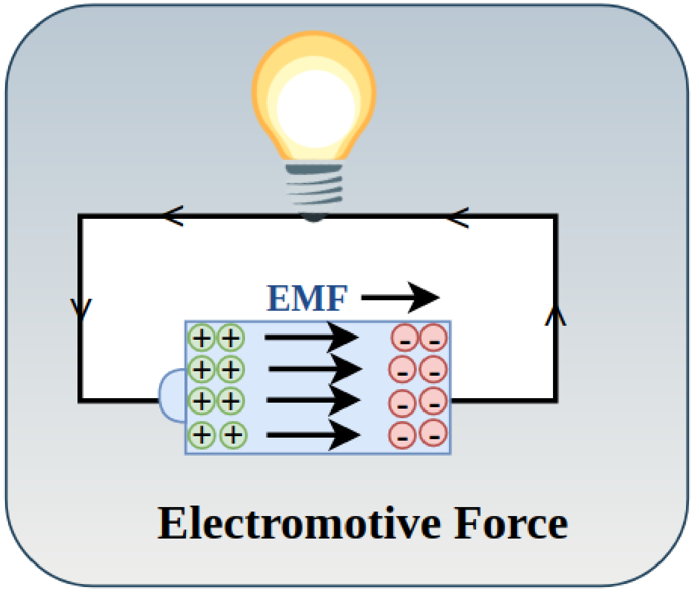
$$E = \frac{W}{q}$$

E = Electromotive force (EMF)

W = Work Done

q = Unit Charge





EMF (Electromotive Force)

- **Formula for EMF of a cell:**

$$E_{cell} = E^o_{cathode} - E^o_{anode}$$

Applications of EMF measurement:

- Determination of Standard Electrode Potentials
- Calculation of Thermodynamic Properties, $\Delta G = -nFE$
- Determination of Equilibrium Constant (K), $E = E^o - (0.0591/n)\log K$
- Determination of Solubility Product (K_{sp})
- pH Measurements
- Study of Corrosion and its Prevention

Electrodics

Electrodics is the study of electrode processes, what happens at the interface of an electrode and an electrolyte.

$$2H^{+}(aq) + e^{-} \rightleftharpoons H_2(g)$$

The electrical energy, $\mathcal{E}$, is directly related to the free energy, ΔG, by the relation,

$$\boxed{\Delta G = -n\mathcal{F}\mathcal{E}}$$

where n is the number of electrons transferred in the process and $\mathcal{F}$ is the Faraday.

For an equilibrium reaction,

$$\boxed{\Delta G = \Delta G^\circ + RT \ln Q}$$

where ΔG^o is the standard free energy and,

$$\boxed{\Delta G^\circ = -RT \ln K_{eq}}$$

$$\Delta G^{\circ} = -RT \ln K_{eq}$$

R is the gas constant equal to 8.314 J/K.mol; T is the absolute temperature; Q is the ratio of the concentration of products to concentration of reactants, and K_{eq} is the value of the equilibrium constant at the specified temperature.

For a chemical reaction, $\Delta G = -n\mathcal{F}\mathcal{E}$ becomes $\mathcal{E} = \mathcal{E}^{o} - RT \ln Q$

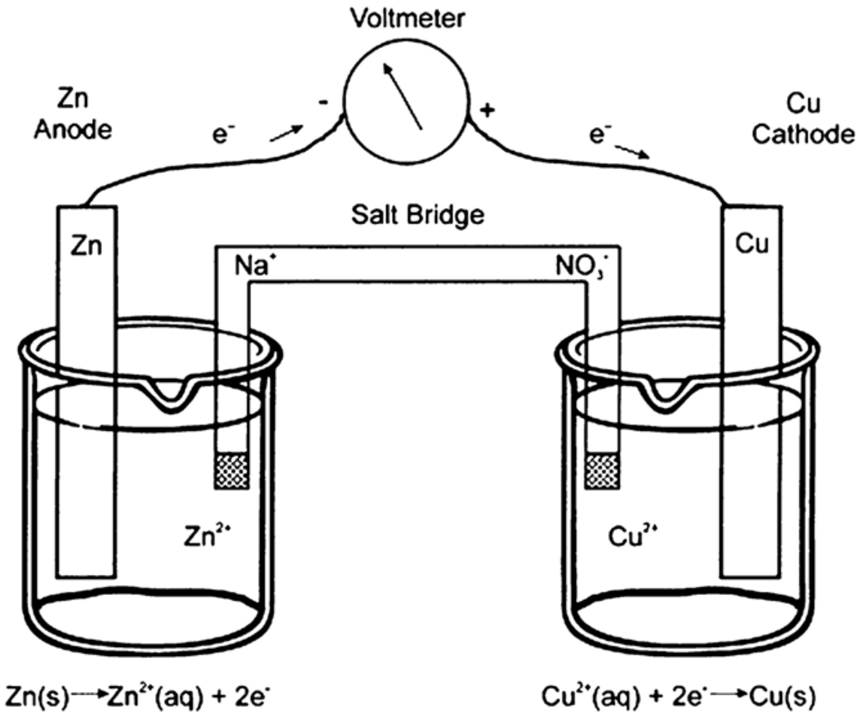
which is called the ***Nernst equation***.

For example, in the Daniell cell, $Zn(s) + Cu^{2+}(qa) \rightarrow Zn^{2+}(aq) + Cu(s)$

$$\mathcal{E} = \mathcal{E}^{o} - \frac{RT}{n\mathcal{F}} \ln \frac{[Zn^{2+}]}{[Cu^{2+}]}$$

Daniell Cell

Daniell cell is a type of electrochemical cell (galvanic cell) that was invented in 1836 by John Frederic Daniell. It is one of the earliest practical batteries and is used to convert chemical energy into electrical energy through a spontaneous redox reaction.



The zinc–copper Daniell cell, where the zinc dissolves at the anode (-) and copper is plated out at the cathode(+)

$$Zn(s) + Cu^{2+}(qa) \rightarrow Zn^{2+}(aq) + Cu(s)$$

half-cell reactions:

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$$

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$$

Shorthand notation:

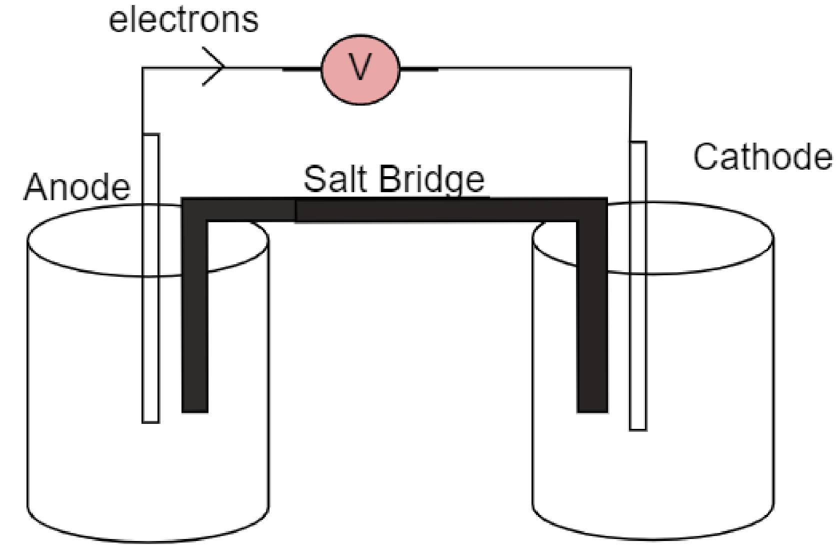
$$Zn|Zn^{2+}(1\,M)||Cu^{2+}(1\,M)|Cu$$

where the single (|) line indicates a phase change and the double (||) line represents a salt bridge or connection between the two half-cells.

Concentration Cell

The simplest cell is one in which the electrode material is the same in each half-cell, but the metal ion concentration is different in the two half-cells. This is called a ***concentration cell***, an example of such a cell is,

$$\mathrm{Cu}\left|\mathrm{Cu}^{2+}(0.01\ \mathrm{M})\right|\left|\mathrm{Cu}^{2+}(0.10\ \mathrm{M})\right|\mathrm{Cu}$$

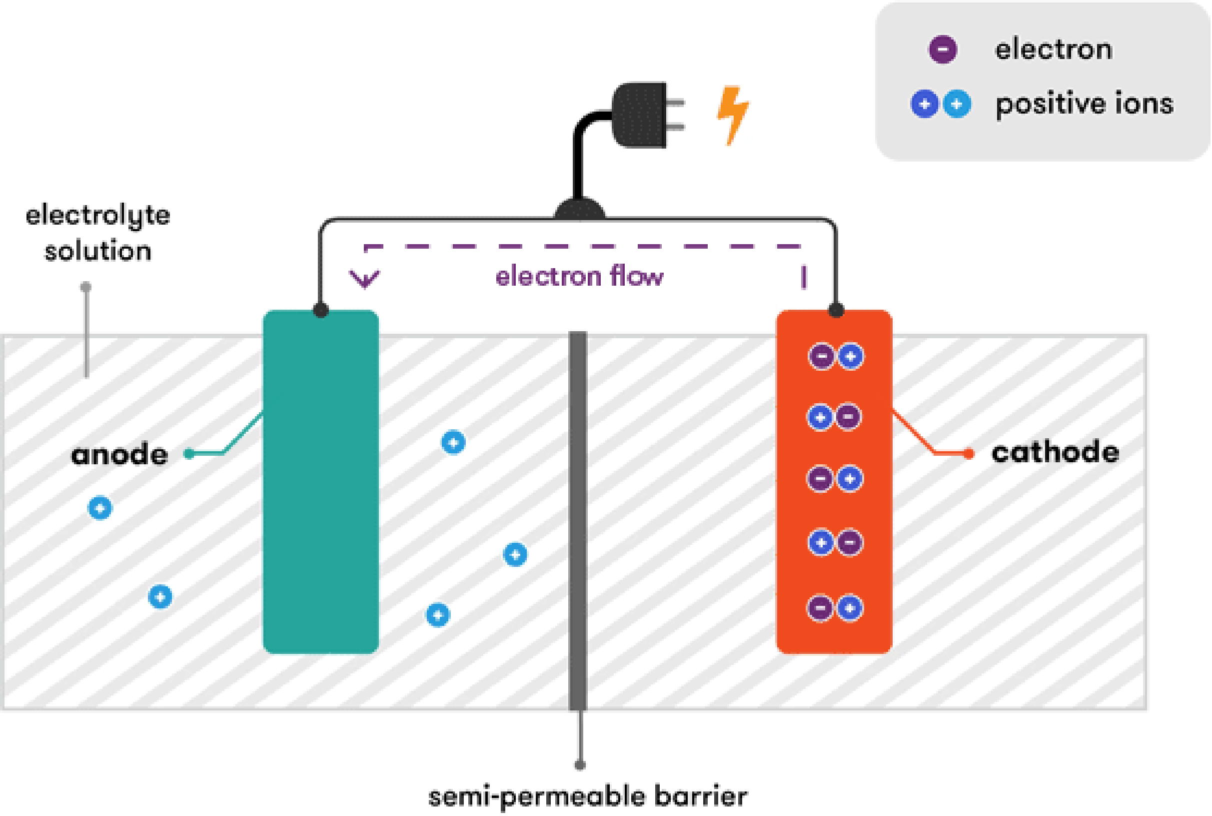


The cell potential is,

$$\mathcal{E}_{cell} = \mathcal{E}^{o}{}_{cell} - \frac{RT}{nF}\ln\frac{0.01}{0.10}, \quad \mathcal{E}_{\mathrm{cell}} = 0 - \frac{0.2568}{2}\ \ln 0.10, \quad \mathcal{E}_{\mathrm{cell}} = 0.0296\ \mathrm{V}$$

Batteries and Cells

The means by which chemical energy is stored and converted into electrical energy is called a ***battery*** or ***cell***.



Types of Batteries or Cells

PRIMARY CELLS VERSUS SECONDARY CELLS

PRIMARY CELLS	SECONDARY CELLS
Primary cells are batteries that cannot be recharged or reused	Secondary cells are batteries that can be recharged and reused
Irreversible reactions occur	Reversible reactions occur
Can be used only once	Can be used more than once
Used in portable devices as they produce current immediately	Needs to be charged before use and are used in automobiles
Have lower self-discharge rates and can be used for long term storage of power	Have a higher self-discharge rate compared to primary cells

BATTERIES

PRIMARY BATTERIES

1. ALKALINE CELLS
2. ALUMINUM AIR CELLS
3. DRY CELLS
4. DANIEL CELLS
5. LECLANCHE CELLS

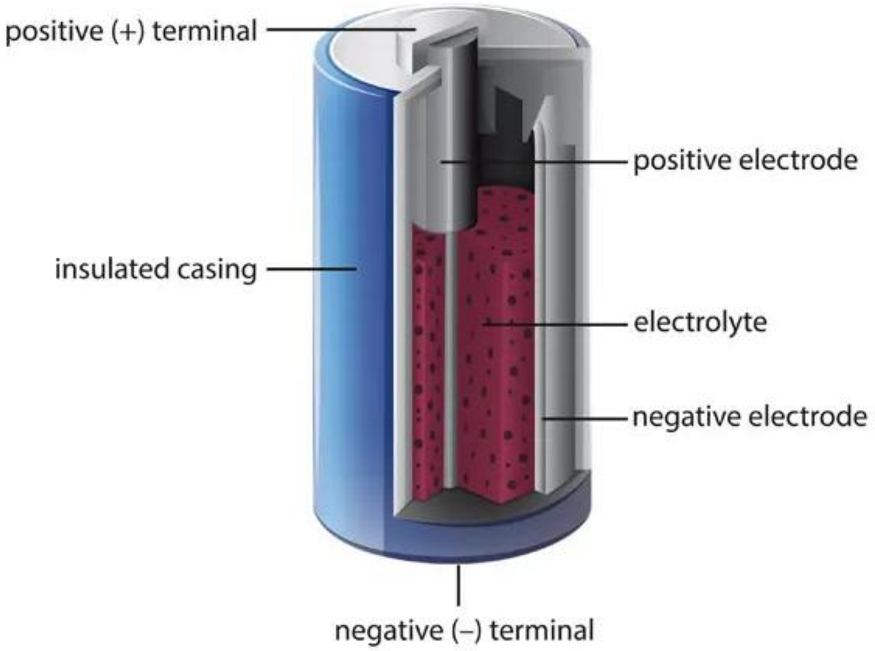
SECONDARY BATTERIES

1. LEAD ACID CELLS
2. LITHIUM ION CELLS
3. NICKEL CADMIUM CELLS
4. SODIUM CELLS
5. ZINC BROMIDE CELLS

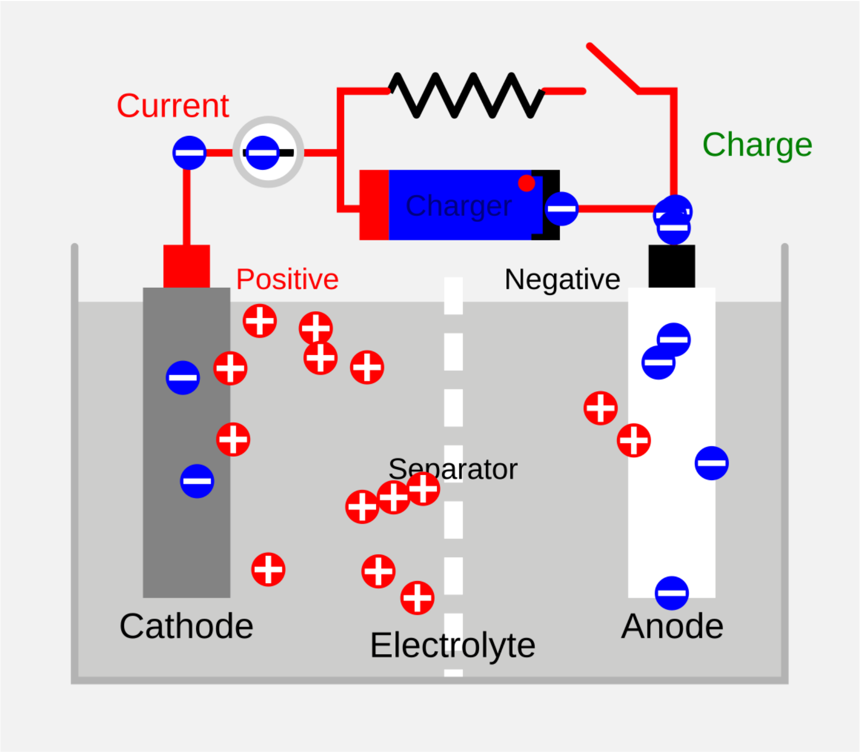
https://www.ufinebattery.com/blog/the-difference-between-primary-and-secondary-battery/

Types of Batteries or Cells

Primary Battery



Secondary Battery



Primary Battery: Alkaline Battery

This is a type of primary (non-rechargeable) electrochemical cell that uses an alkaline electrolyte (potassium hydroxide, KOH) instead of the acidic ammonium chloride or zinc chloride used in older zinc-carbon batteries. It was invented in 1959 by Lewis Urry.

At the anode (oxidation):

$Zn(s) + 2OH-(aq) \rightarrow ZnO(s) + H2O(l) + 2e^{-}$

At the cathode (reduction):

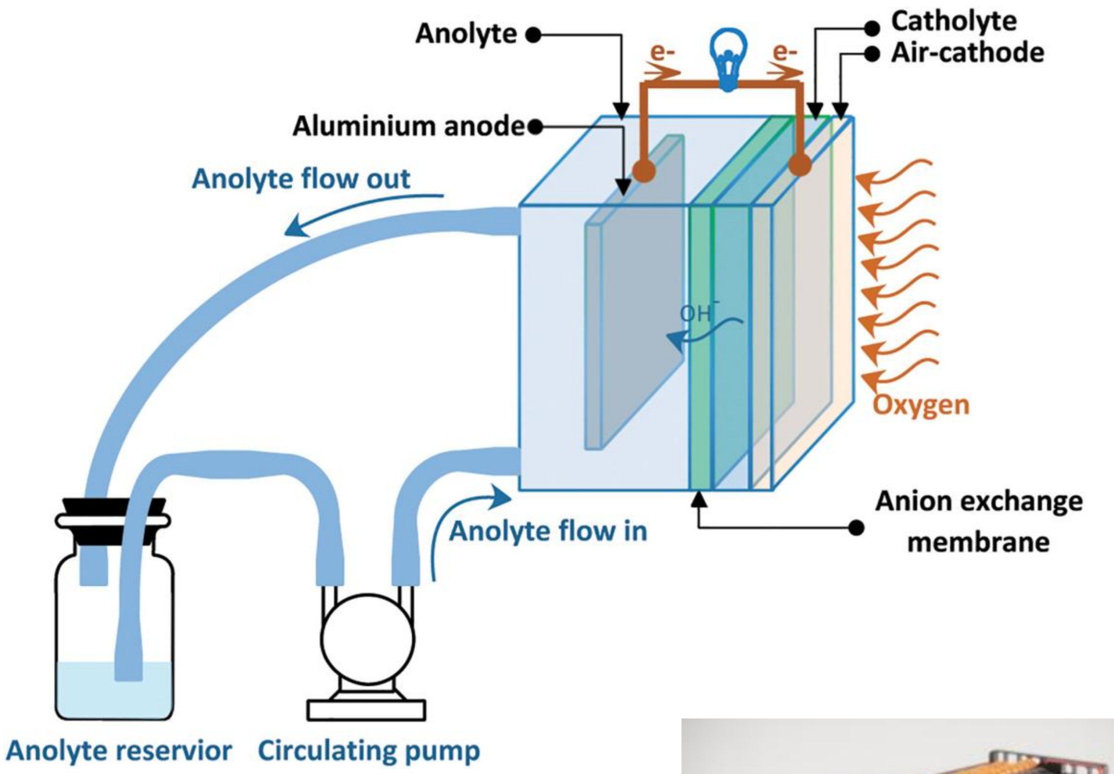
$2MnO_2(s) + H_2O(l) + 2e^{-} \rightarrow Mn_2O_3(s) + 2OH^{-}(aq)$

Overall reaction:

$Zn(s) + 2MnO_2(s) \rightarrow ZnO(s) + Mn_2O_3(s)$

Primary Battery: Aluminium–air battery

It is a type of metal-air electrochemical cell that produces electricity from the reaction of aluminium (Al) with oxygen (O_2) from the air.



At the anode (oxidation):

$Al(s) + 3OH^-(aq) \rightarrow Al(OH)_3(s) + 3e^-$

At the cathode (reduction):

$(3/4)O_2(g) + (3/2)\ H_2O(l) + 3e- \rightarrow 3OH-(aq)$

Overall reaction:

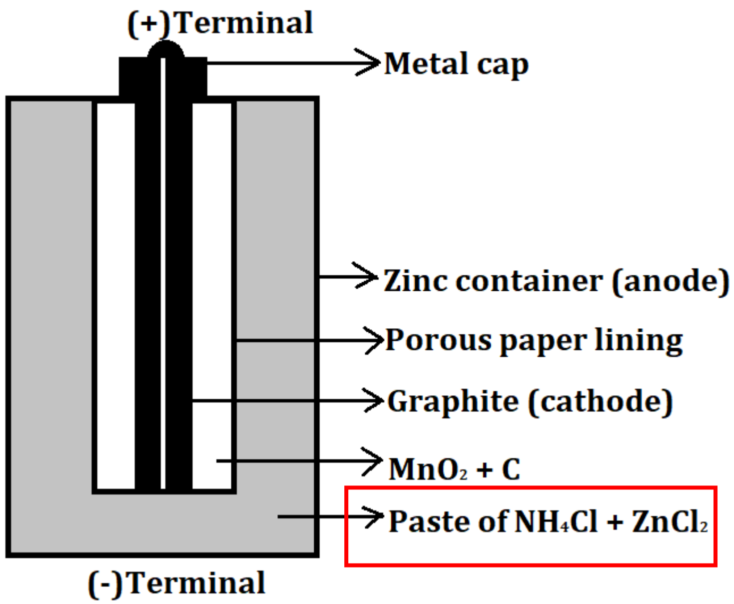
$4Al(s) + 3O_2(g) + 6H_2O(l) \rightarrow 4Al(OH)_3(s)$

Primary Battery: Dry Cell

A Dry Cell is the most common type of primary (non-rechargeable) battery, widely used in torches, toys, clocks, remotes, etc. It is a type of zinc–carbon cell, developed to be more convenient than older wet cells because it contains no free liquid electrolyte (so it can be used in any position without spilling).

At the anode (oxidation):

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$



At the cathode (reduction):

$2MnO_2(s) + 2NH_4^+(aq) + 2e^- \rightarrow Mn_2O_3(s) + 2NH_3(aq) + H2O(l)$

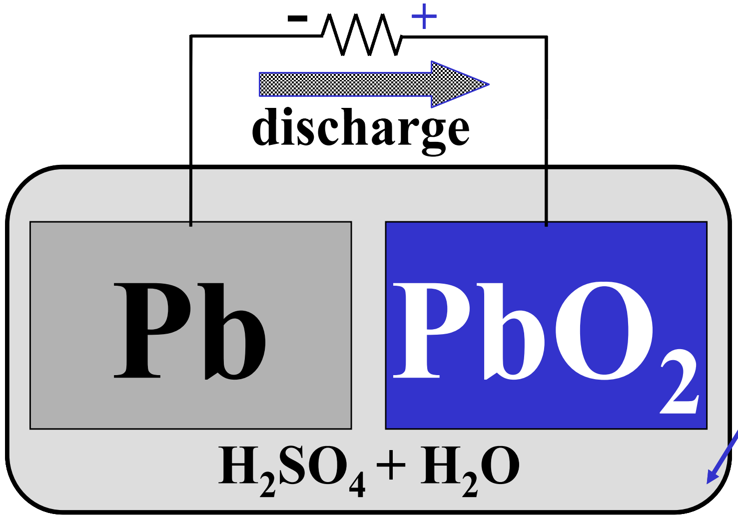
Overall reaction:

$Zn(s) + 2MnO_2(s) + 2NH_4^+(aq) \rightarrow Zn^{2+}(aq) + Mn_2O_3(s) + 2NH_3(aq) + H_2O(l)$

http://dx.doi.org/10.7763/IJESD.2016.V7.768

Secondary Battery: Lead-Acid Battery

A lead-acid battery is the oldest rechargeable battery (invented in 1859 by Gaston Planté) and is still widely used today, especially in cars, trucks, inverters, and backup power systems.



As the cell discharges, more water is formed, lowering the specific gravity of the electrolyte.

At the anode (oxidation):

$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$

At the cathode (reduction):

$PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$

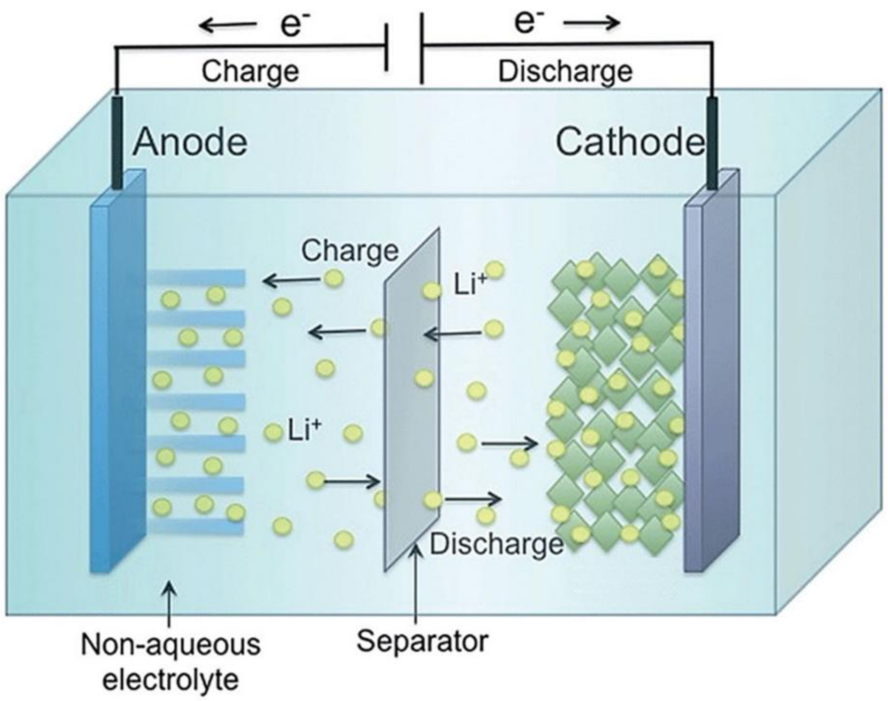
Overall reaction:

$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

https://www.mrpositive.co.nz/buying/knowledge-base/lead-acid-battery-types/?srsltid=AfmBOoopcaueFnAMy2bJCkaBOuVUpXPIFDDiZQAviqCuxpKvUdsB0Y4W

Secondary Battery: Li-ion Battery

A Lithium-ion (Li-ion) battery is a rechargeable electrochemical battery that stores and releases energy through the movement of lithium ions (Li^+) between the electrodes. It is the most widely used battery in laptops, smartphones, electric vehicles (EVs), and energy storage systems because of its high energy density and long cycle life.



At the anode (oxidation):

$LiC_6 \rightarrow C_6 + Li^+ + e^-$

At the cathode (reduction):

$Li_{1-x}CoO_2 + xLi^+ + xe^- \rightarrow LiCoO_2$

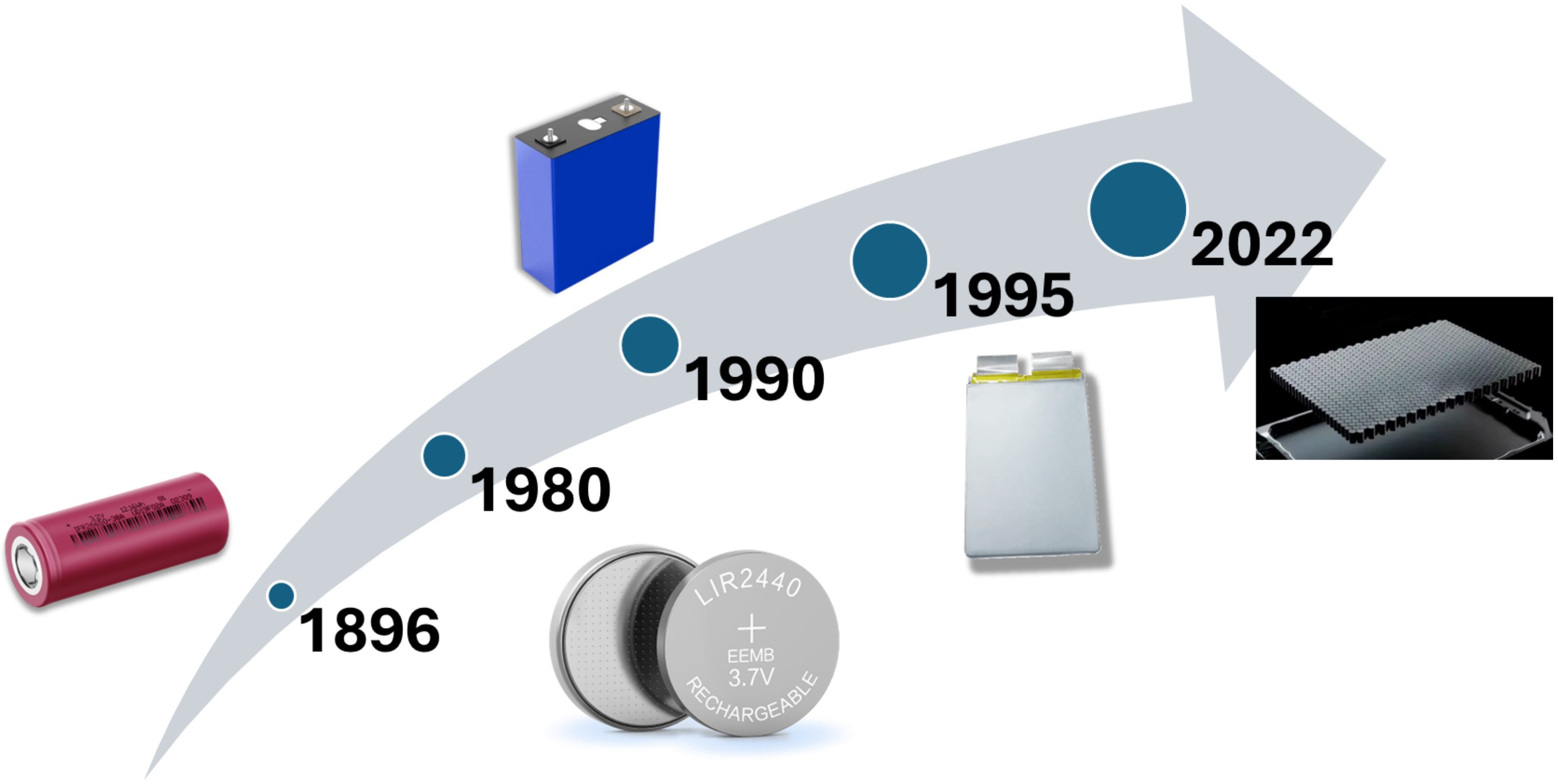
Overall reaction:

$C_6 + LiCoO_2 \rightarrow LiC_6 + CoO_2$ (During Charging)

$LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2$ (During Discharging)

Types of Battery Format

Battery Formats: Cylindrical cell, Coin Cell, Prismatic Cell, Pouch Cell, Hexagonal Prism Battery, Tab-less Battery



https://batteryuniversity.com/article/bu-301a-types-of-battery-cells

Cylindrical Cell: Structure and components

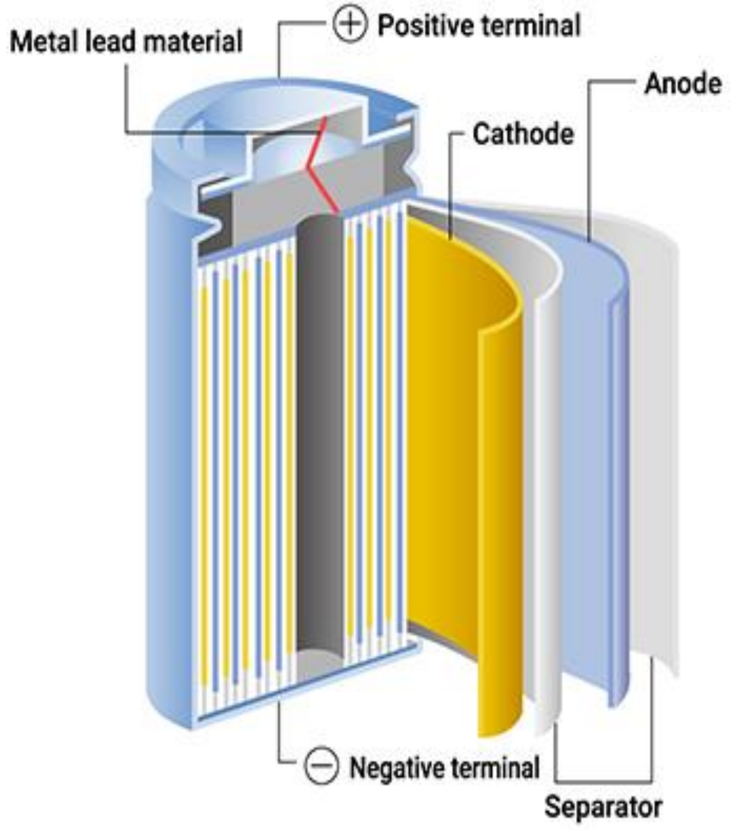


Figure. Graphical representation of a cylindrical battery

Shape & Structure:

- Cylindrical metal can (usually steel or aluminum).
- Contains rolled layers of cathode, separator, and anode (called a "**jelly roll**").
- Most are Li-ion ($LiCoO_2$, NMC, NCA, $LiFePO_4$, etc.).

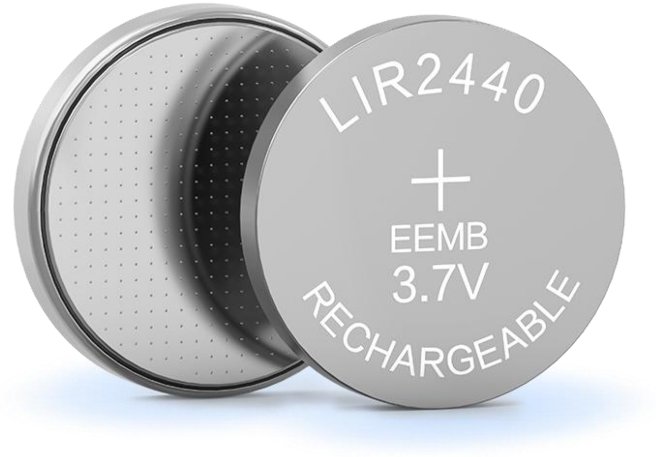
Advantages:

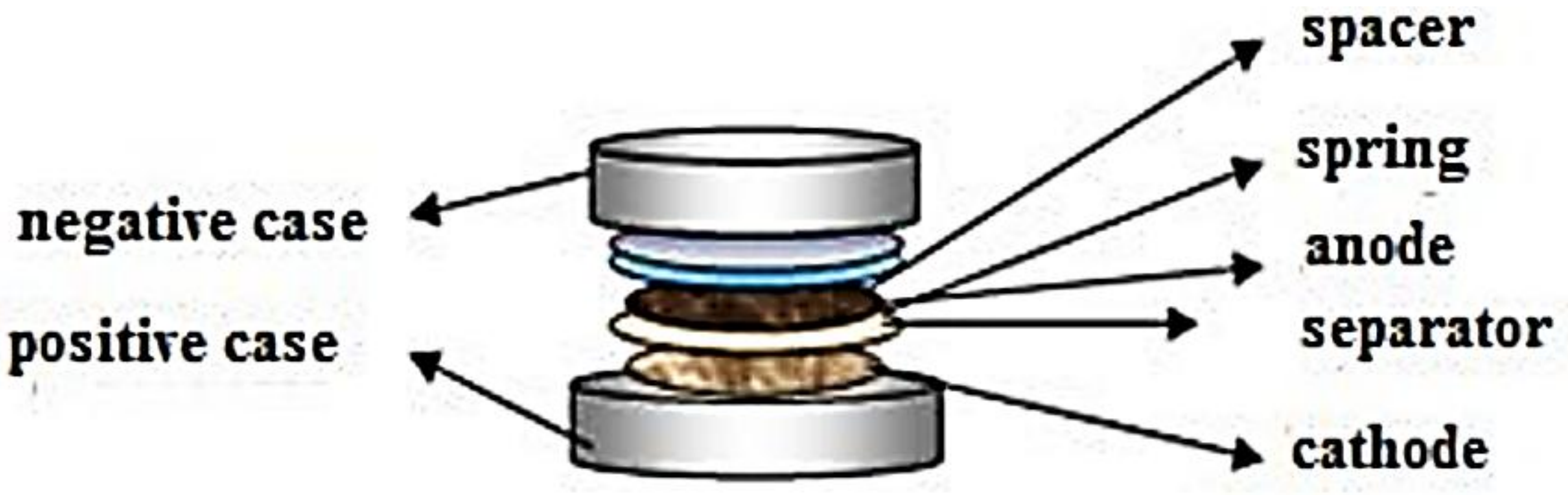
- ✓ Strong mechanical design (metal casing resists swelling).
- ✓ Good thermal management.
- ✓ Easier to manufacture in large volumes (low cost).
- ✓ Reliable with long cycle life.

Disadvantages:

- ✓ Space utilization is lower (gaps between cylinders in packs).

Coin Cell: Components



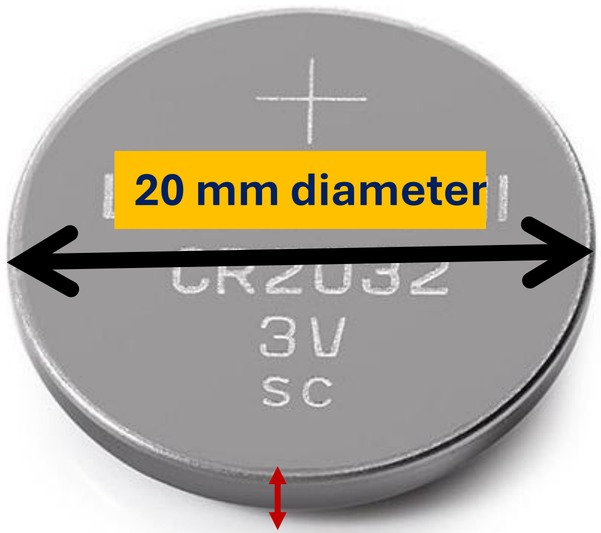


Anode: usually made of **Zn** or **Lithium**

Cathode: Usually made of manganese dioxide, silver oxide, carbon monofluoride, or copper oxide.

Electrolyte: common electrolyte in Li-ion battery ($LiPF_6$ + EC/DMC/DEC solvent)

Coin Cell: Naming

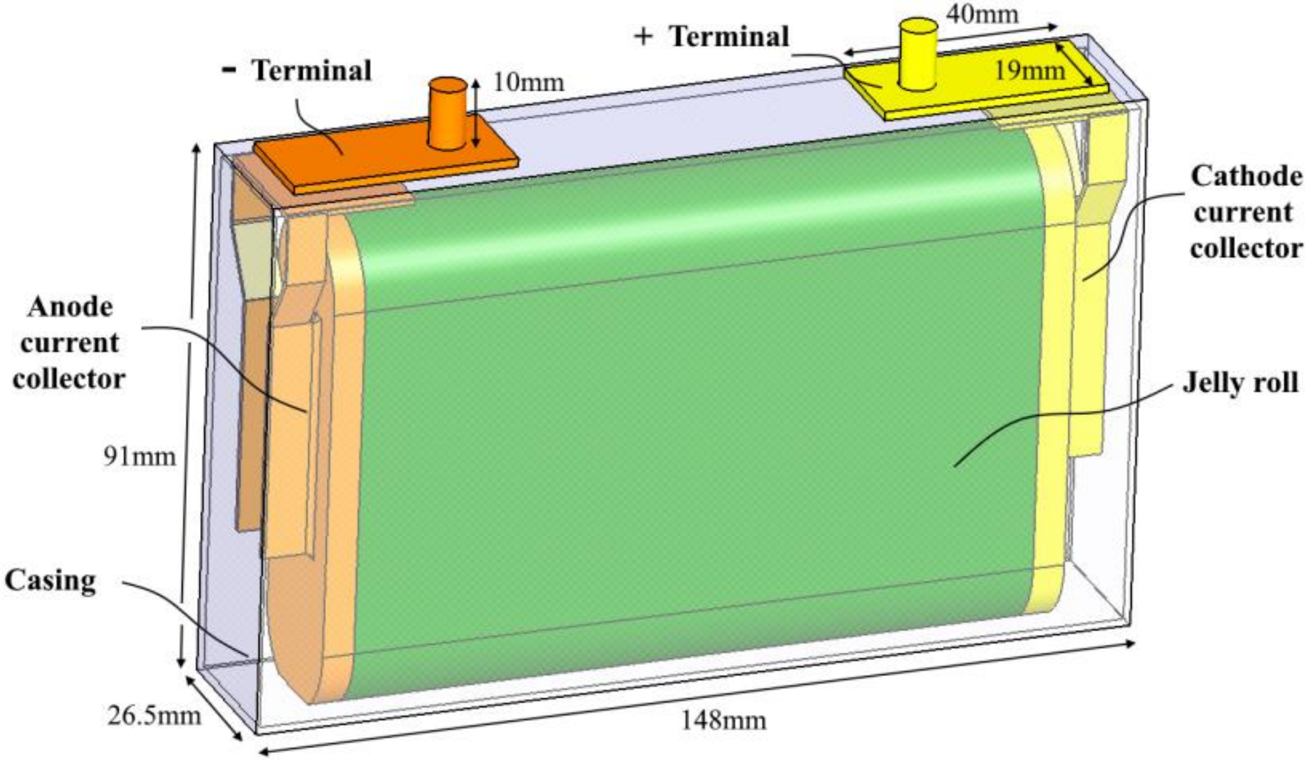


3.2 mm thickness

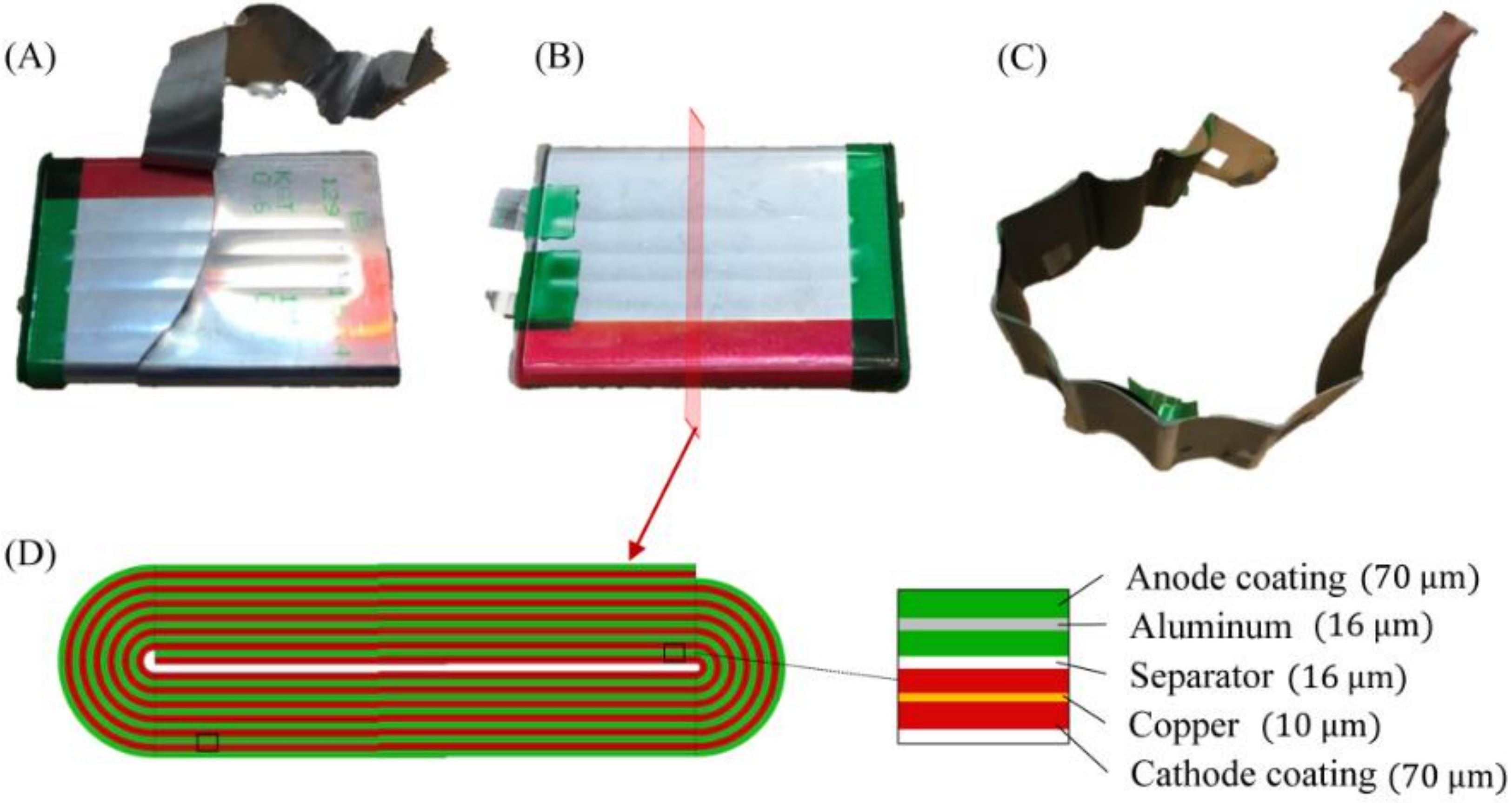
CR2032

First letter: Chemistry of the cell C: Lithium Coin Cell L: Alkaline cell	**Second letter:** shape of the cell R: Round S: Square F: Flat P: Not round	20	32

Prismatic Cell: Components



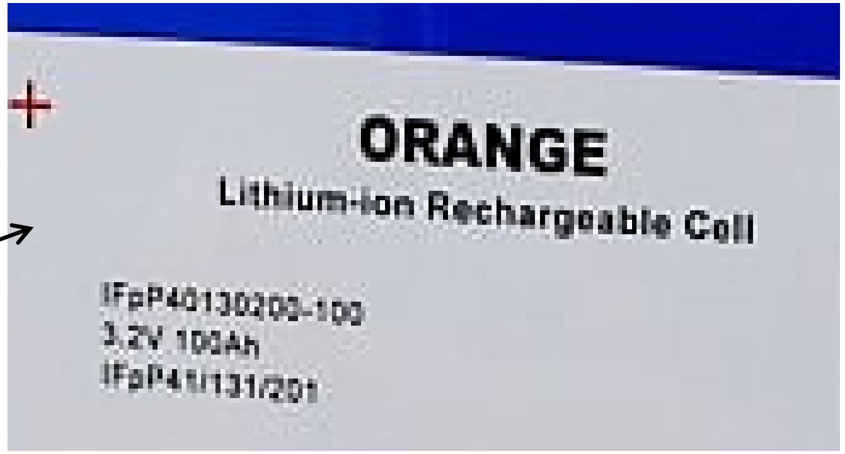
Prismatic Cell: Components



The disassembled prismatic cell. (A) and (B) Shell casing and jellyroll, (C) unfolded jellyroll, (D) illustration of the jellyroll cross-section and the thickness of each layer.

Li et al. *EcoMat*, **2022**, 4(6).

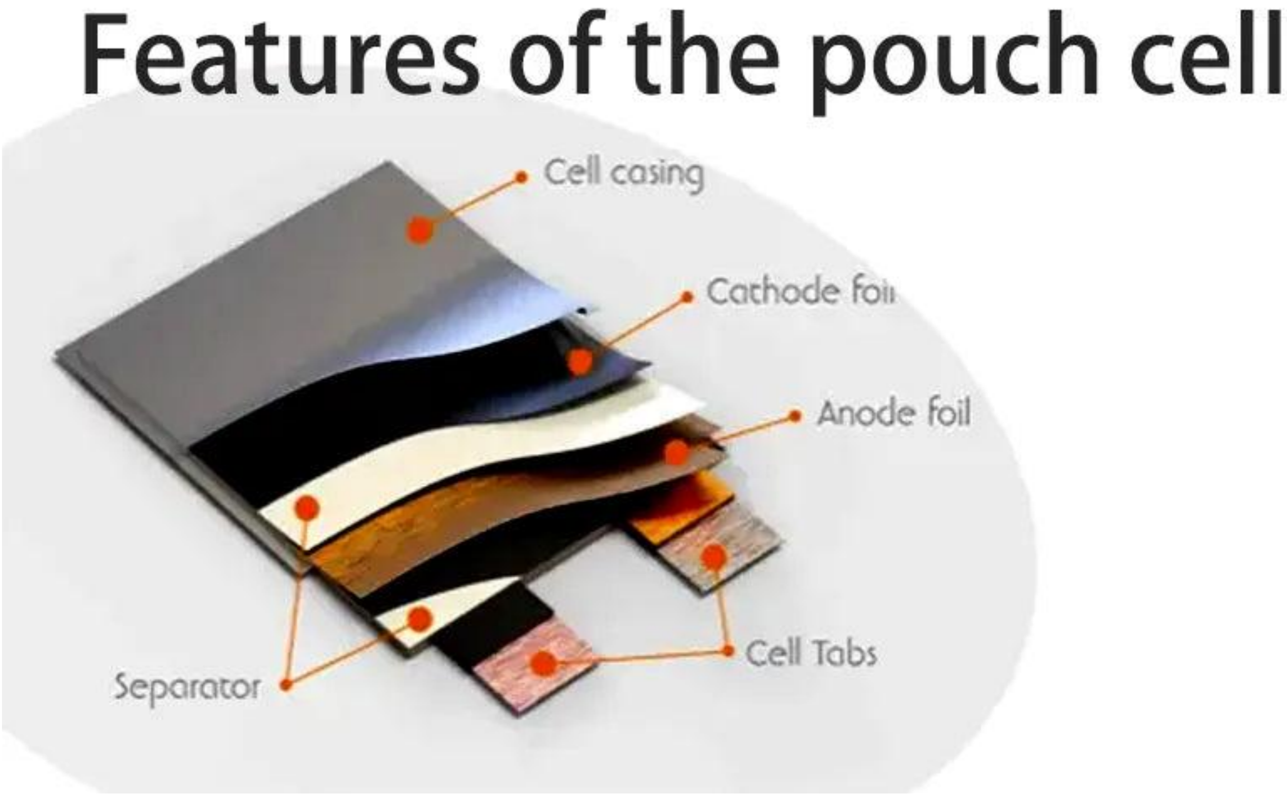
Prismatic Cell: Naming



P40130200

prismatic cell, 4.0 mm thick, 130 mm wide, and 200 mm long

Pouch Cell: Components

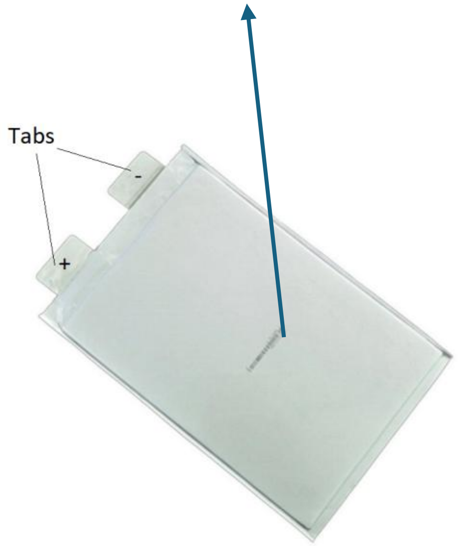


Pouch Cell: Naming

Here is an example of how to name a pouch cell:

- First three letters: The cell's chemistry
- Numbers: The cell's outer dimensions
- First two numbers: The thickness of the cell in millimeters
- Third and fourth numbers: The width of the battery in millimeters
- Last two numbers: The height of the battery in millimeters
- sometimes normal capacity also mention

LII12268228 3267



Chemistry: **lithium-ion (LII)**
Thickness: 12 mm, Width: 268 mm, Height: 228 mm, Normal capacity: 3267

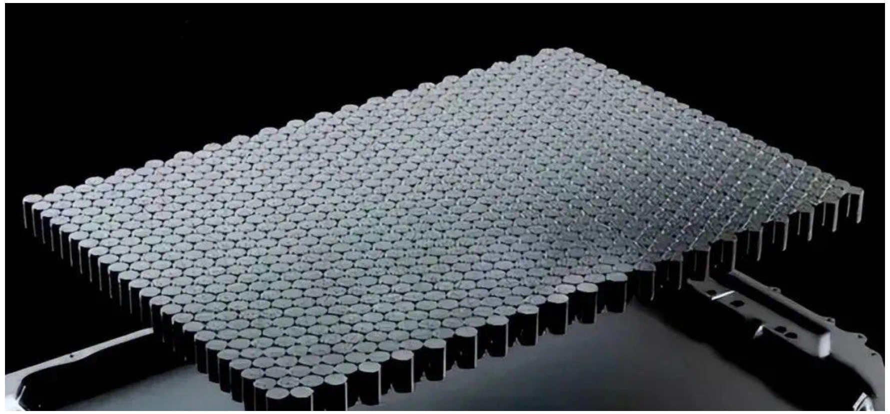
First three letters: LII for lithium-ion
Dimension numbers: 12268228
Normal capacity: 3267
The final name would be **LII122682283267**.

Hexagonal Prism Cell

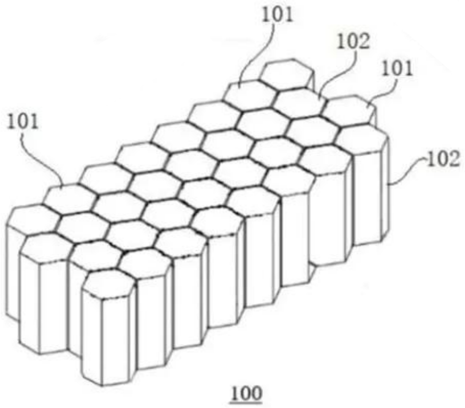
Hexagonal Prism Battery Cells:

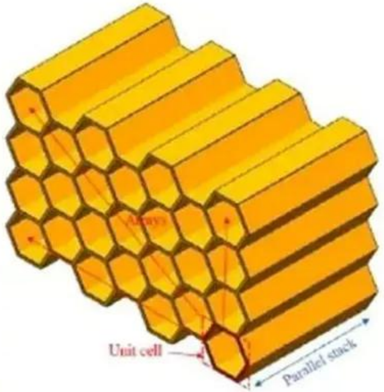
1. These cells have a distinctive hexagonal column shape, resembling a honeycomb structure.

2. The inspiration for this design likely comes from nature’s honeycomb, which optimizes space utilization and energy density.

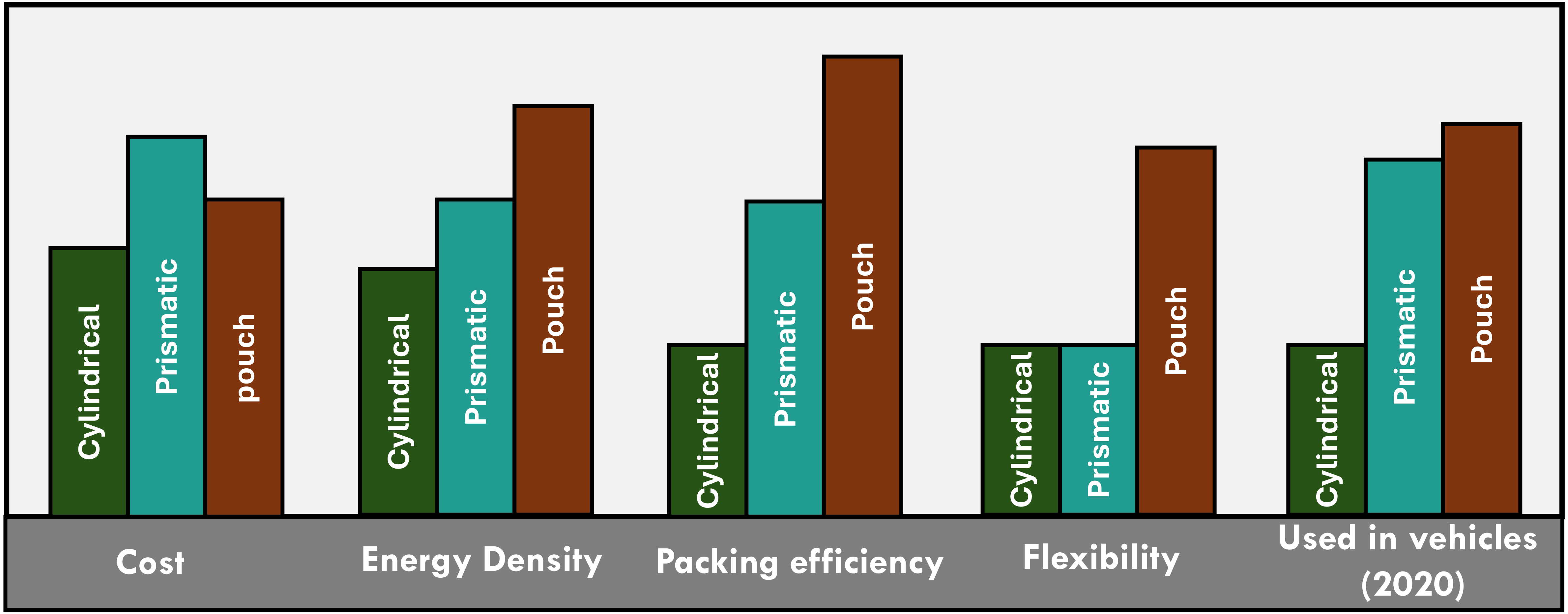


BYD hexagonal prism cell





Comparison between different cell formats



https://www.addionics.com/post/pouch-cylindrical-or-prismatic-which-battery-format-will-rule-the-market

Solid State Battery

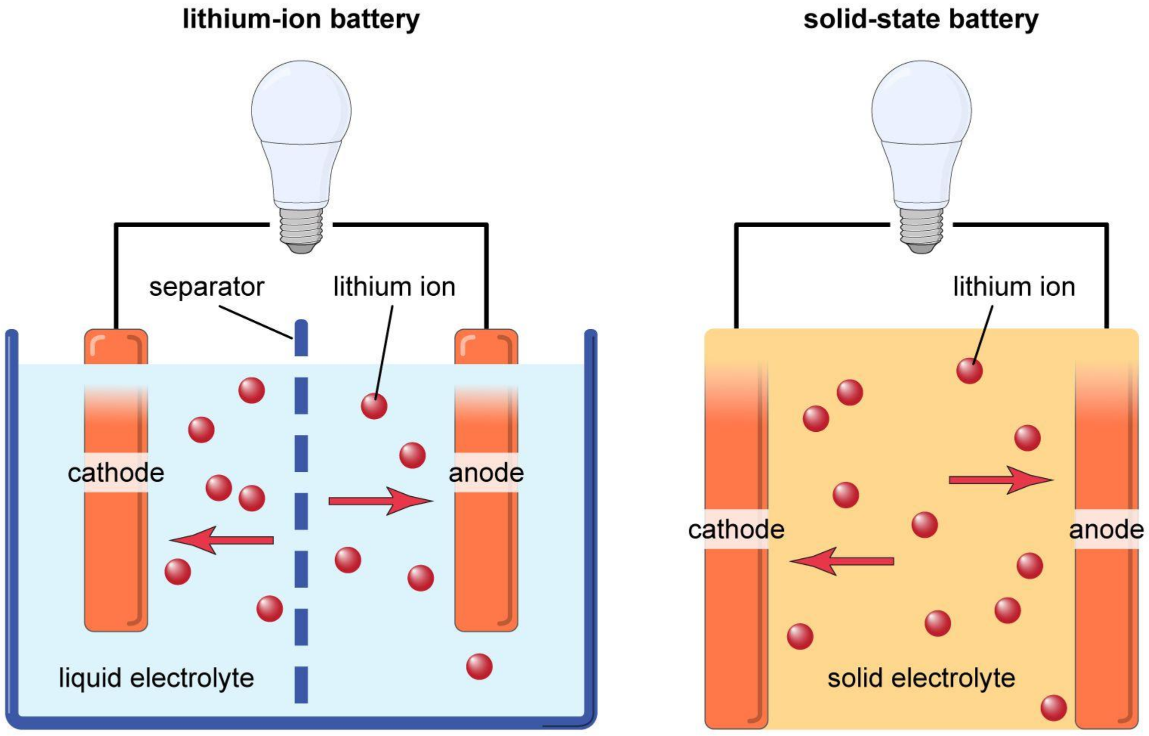
A solid-state battery is a next-generation rechargeable battery in which the liquid electrolyte of conventional lithium-ion batteries is replaced by a solid electrolyte. This solid electrolyte can be ceramic, glass, polymer, or a composite material.

Advantages:

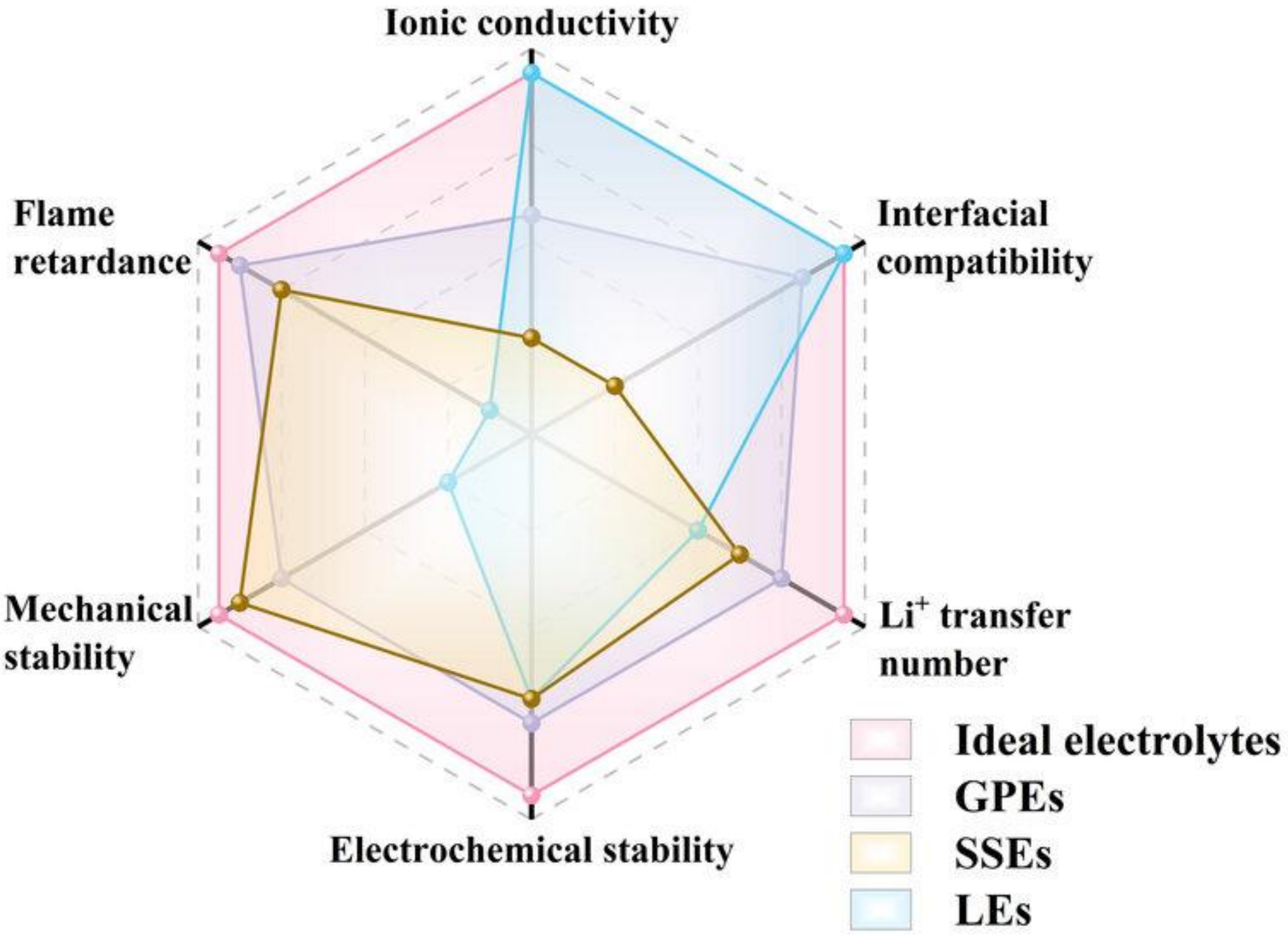
- **Higher energy density** (because lithium metal anodes can be used).
- **Safer** (no flammable liquid electrolyte, lower risk of fire/explosion).
- **Longer cycle life** (less degradation).
- **Can work in wider temperature ranges.**

Challenges:

- **lower ionic conductivity** than liquid electrolyte.
- Manufacturing is complex and costly.
- Still in **research and development**, not yet mass-produced at low cost.



Solid vs Liquid Electrolyte in Battery



Energy Mater. **2024**, *4*, 400061. http://dx.doi.org/10.20517/energymater.2023.144