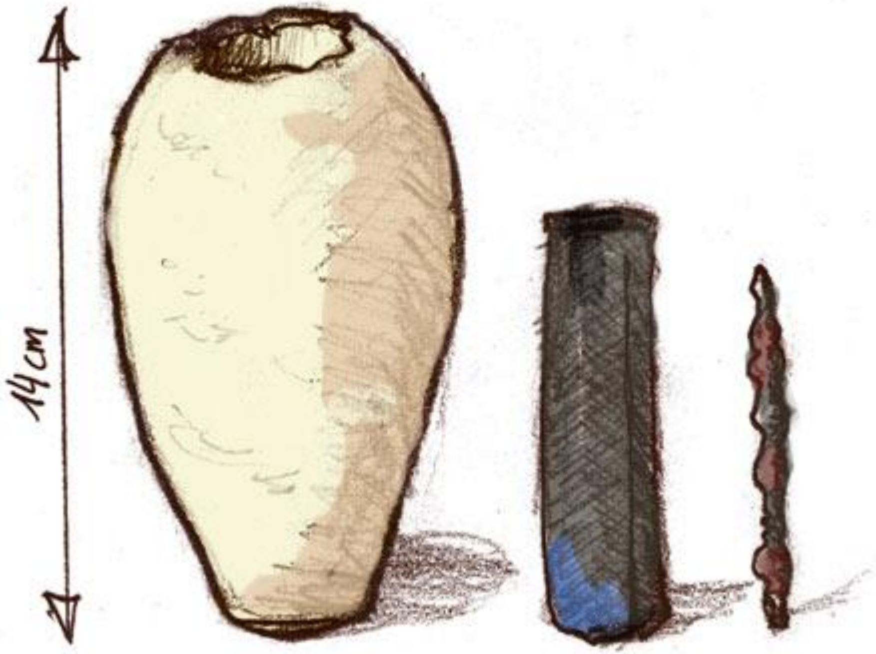
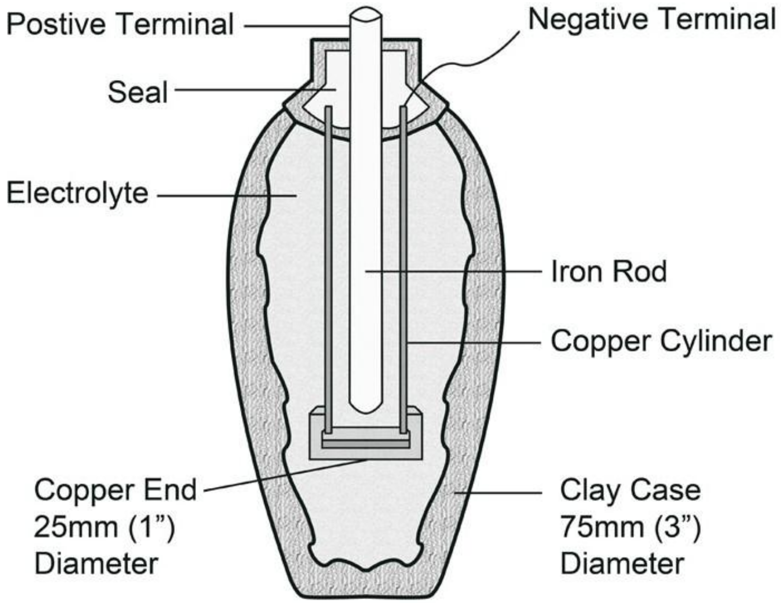
BATERIAS

Sistemas Electroquímicos de Conversión y Almacenamiento de Energía

- Generación de Energía
  - Big Bang (nuclear)
  - Sol (fotosíntesis, petróleo, carbón, eólica, mareomotriz, celdas entrópicas)
- Conversión de Energía
    - Celdas de combustible
    - Hidroelectricidad
    - Molinos de viento
    - Paneles solares
- Almacenamiento de Energía
  - Hidrogeno, metanol, etc.
  - Baterías
  - Supercapacitores
- Baterías
  - Celda galvánica
  - Pila
  - Batería
    - Primarias
    - Secundarias (recargables)
- Celdas de Combustible
- Supercapacitores
  - Doble capa
  - Redox

La batería de Bagdad
250 ac -240





En 1939 el arqueólogo alemán Wilhelm König lo identifica como una posible pila eléctrica. Despues de 1945 Willard Gray, ingeniero en electrónica del Laboratorio de Alto Voltaje, de la General Electric Company, de Pittsfield (Massachussets, EE. UU.), fabricó un duplicado de estas baterías obteniendo 1-2 V.

El 11 de abril de 2003, durante la Invasión de Irak, el Museo Nacional de Irak en Bagdad, fue asaltado y saqueado y se destruyeron las baterias de Bagdad.

https://es.wikipedia.org/wiki/Bater%C3%ADa_de_Bagdad

Baterías

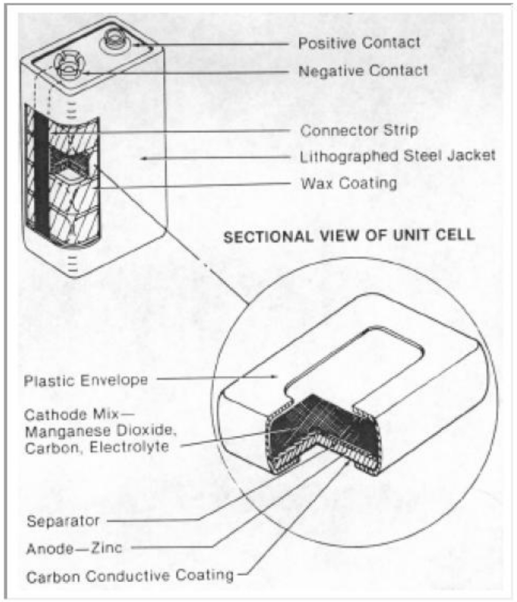


Fig. 4. Flat Leclanche cell and battery assembly. (Courtesy Eveready Battery Co., Inc.)

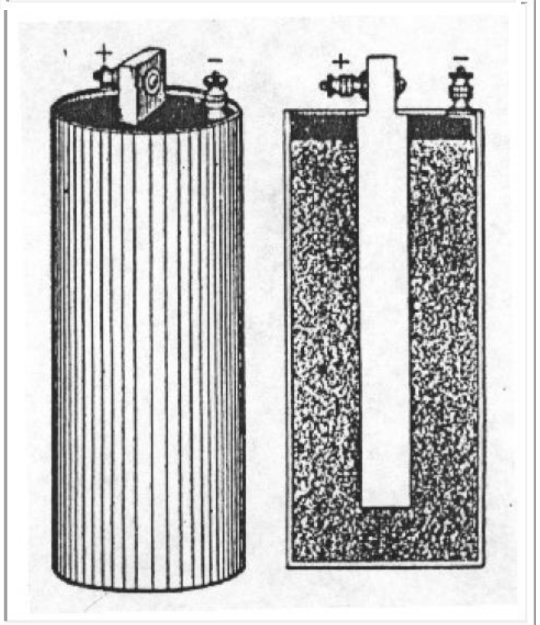


Fig. 2. Early "6-inch" cell. (Courtesy Eveready Battery Co., Inc.)

Fig. 1. Examples of commercial Leclanche cells from the 1960's. (Courtesy Eveready Battery Co., Inc.)

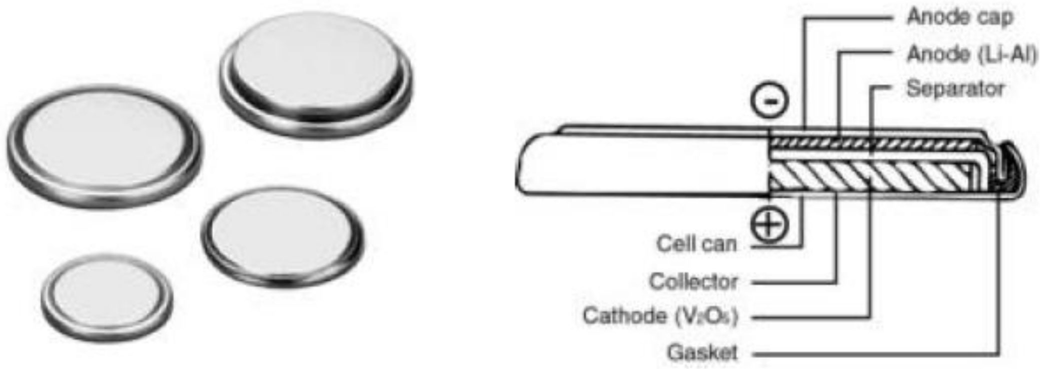


Figure 3-2: **The button cell.**

Fuerzas Impulsoras del Desarrollo de Sistemas de Conversión y Almacenamiento de Energía

- 1799-1800 Galvani vs. Volta
- 1838 Celda de Combustible de Grove.
- Expansión Territorial y Telégrafo: 1836 Celda de Daniel y 1966. Lechanche. Linternas.
- 1959 Radio portátil a transistores (1947) Baterias alcalinas. Linternas.
- 1960- Carrera Espacial (Gemini) Desarrollo de celdas de Combustible alcalinas
- 1973. Crisis del Petroleo: GM batería Ni/Cd, Celdas de Combustible acido fosfórico
- 1960/70 Baterías para uso militar de alta energía Li/SO2Cl
- 1960/70 Baterías Zn/aire para audífonos.
- 1970 Descubrimiento de inter-capación de litio en grafito.
- 1980 Electrónica portátil. Baterías Ni-MH
- John Goodenough inserción Li en óxidos para cátodos.
- 1981 Sony batería Li ion. Electronica portatil. Laptops, telefonos, tablets.
- Impulso de las Energías limpias.
- 2000 Impulso autos eléctricos. Celdas de combustible, super-capacitores.
- Baterías de alta densidad de energía para autos eléctricos

Galvani

Inlaid into the wooden floor of the basement at the Faraday Museum of the Royal Institution in London is a representation of a plump, green frog. The mosaic serves as a salutary reminder that all of today's electronic marvels began with the twitching of a frog's leg. In Luigi Galvani's (1737-1798) own words:

"I had dissected and prepared a frog in the usual way and while I was attending to something else I laid it on a table on which stood an electrical machine at some distance from its conductor and separated from it by a considerable space. Now when one of the persons present touched accidentally and lightly the inner crural nerves of the frog with the point of a scalpel, all the muscles of the legs seemed to contract again and again as if they were affected by powerful cramps."

The twitchings were, almost literally, the birth pangs of electrophysiology, and they were soon to show the way to the voltaic pile and current electricity.

In a very careful series of experiments in which he fastened "brass hooks in their [the frogs'] spinal cord to an iron railing which surround a certain hanging garden of my house" Galvani noticed that the frogs' legs went into contractions "not only when the lightning flashed but even at times when the sky was quiet and serene." In the contact between the brass hooks and the iron railing, Galvani came tantalizingly close to the contact theory later advanced by his fellow-countryman, Allesandro Volta. However, Galvani chose to interpret his results in terms of "animal electricity," which proclaimed that the structure of the muscle retained a "nerveo-electrical fluid" similar to that of an electric eel.

Shortly before he died, Galvani was dismissed from his professorship at the University of Bologna, because he refused to swear allegiance to Napoleon's Cisalpine Republic. As the Dictionary of Scientific Biography poignantly states: Galvani "died in poverty and sorrow."

PILA DE ALESSANDRO VOLTA

Figure 1-1: **Alessandro Volta, inventor of the electric battery.**

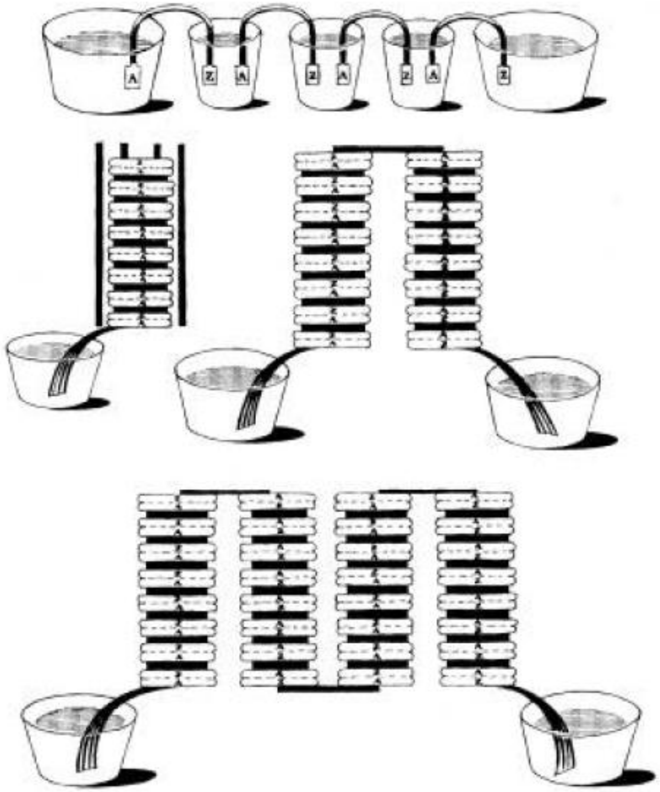
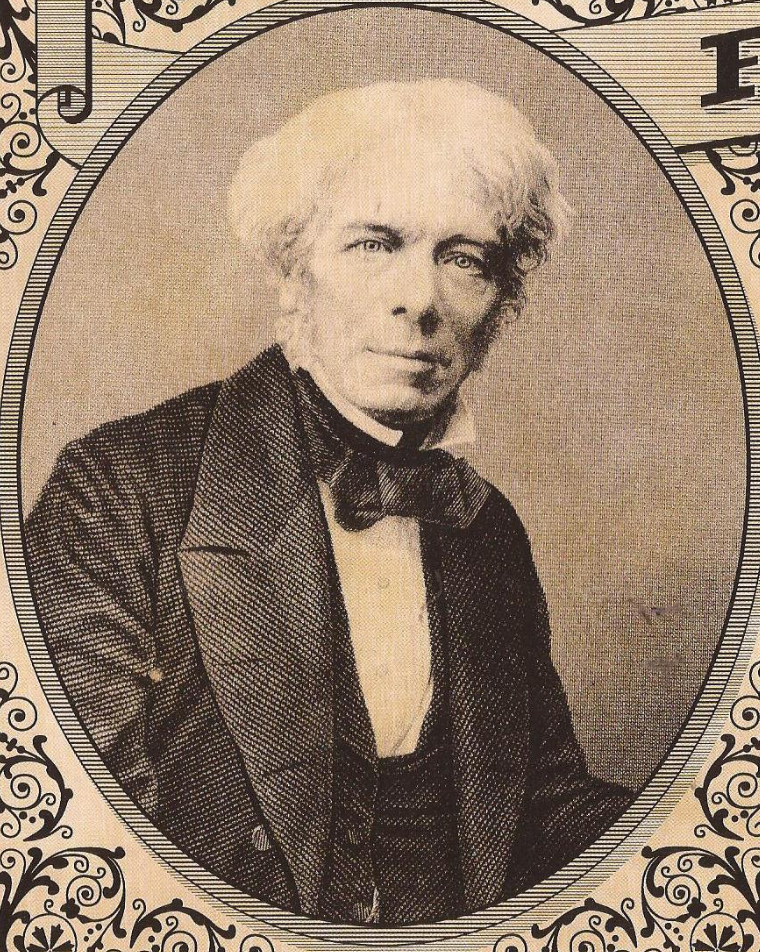


Figure 1-2: Four variations of Volta's electric battery.
Silver and zinc disks are separated with moist paper. ©Cadex Electronics Inc.

Faraday



To omit the mention of Humphry Davy from any discussion of Michael Faraday's (1791-1867) contribution to electrochemistry would be to omit an essential element of a key equation.

Davy was Faraday's mentor in his early years of physics and electrochemistry research. For a time, in fact, Faraday extended and developed the research begun by Davy at the Royal Institution in London, where Faraday began his career in 1813 as Davy's Laboratory Assistant. Most of Faraday's early experiments — and published papers — bore the stamp of Davy's involvement.

Faraday achieved scientific prominence of his own for the First Law of Electrochemistry, developed in 1834: "The chemical power of a current of electricity is in direct proportion to the absolute quantity of electricity which passes."

The Second Law of Electrochemistry, also defined by Faraday, states: "Electrochemical equivalents coincide, and are the same, with ordinary chemical equivalents."

The work that led to these two laws also resulted in many of the modern electrochemical terms — electrode, electrolyte, and ion, to name a few — all coined by Faraday.

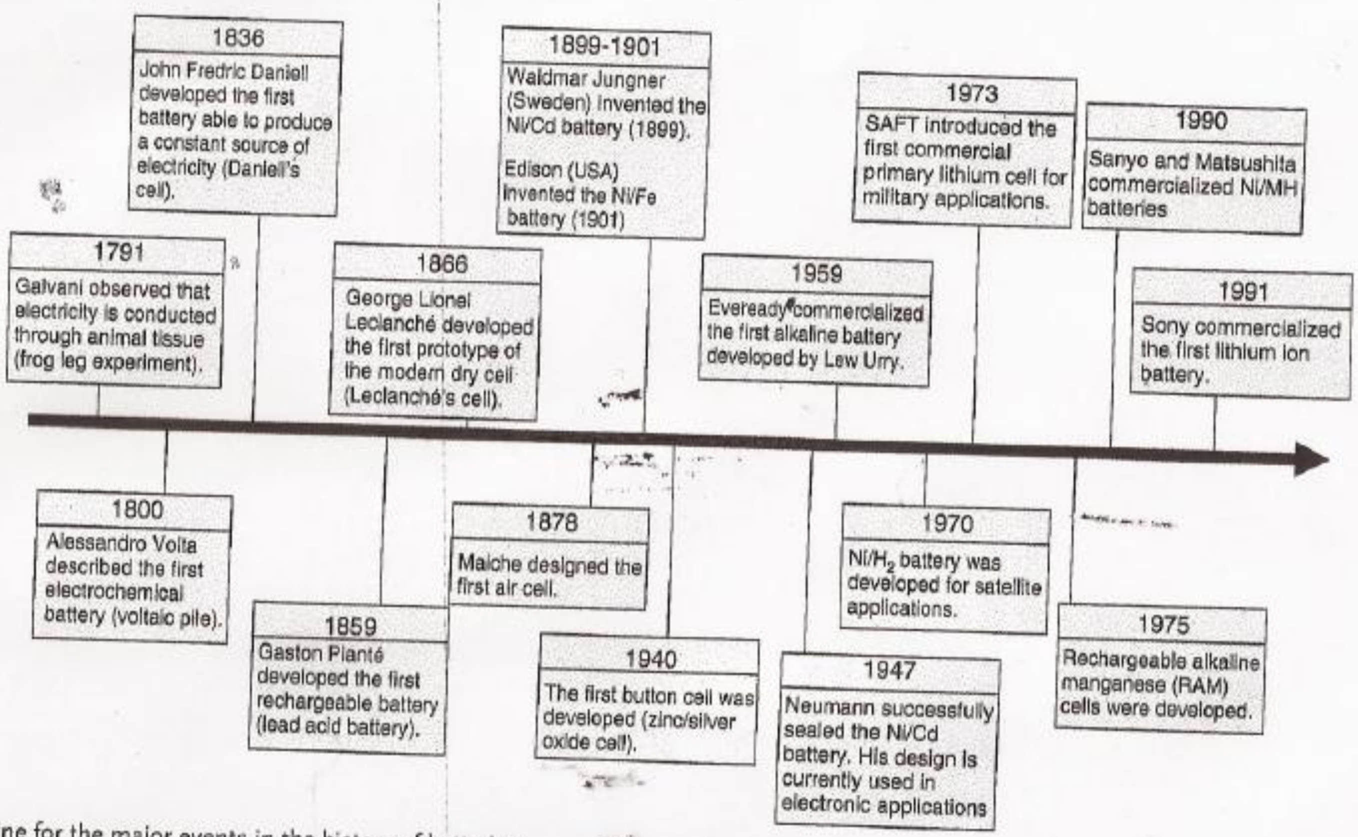
But Faraday didn't consider himself an electrochemist; he preferred the title of "natural philosopher" and devoted his life to proving the interconnection of natural forces. His electrochemical research was one outcome of this effort, exploring the connection between the chemical and electrical forces of the voltaic battery. Among Faraday's greatest accomplishments are:

- His discovery of electromagnetic induction and the related development of the first transformer, electric generator, and the electric motor.
- Development of fundamental laws of electromagnetism.
- Discovery of the "Faraday Effect", the rotation of the plane of polarization of light by a magnetic field (which later served as the foundation for the field of magneto-optics).
- Discovery of paramagnetism and diamagnetism

Faraday was also a superb lecturer and initiated two lecture series, the "Friday Evening Discourses" and the "Christmas Lectures" at the Royal Institution. Both series continue to this day. Though he arose from very humble beginnings, left school at the age of 12 and was essentially self-taught, Faraday came to be respected as one of the greatest of all scientists.

History of Battery Development

1600	Gilbert (England)	Establishment electrochemistry study
1791	Galvani (Italy)	Discovery of ‘animal electricity’
1800	Volta (Italy)	Invention of the voltaic cell
1802	Cruickshank (England)	First electric battery capable of mass production
1820	Ampère (France)	Electricity through magnetism
1833	Faraday (England)	Announcement of Faraday’s Law
1836	Daniell (England)	Invention of the Daniell cell
1859	Planté (France)	Invention of the lead acid battery
1868	Leclanché (France)	Invention of the Leclanché cell
1888	Gassner (USA)	Completion of the dry cell
1899	Jungner (Sweden)	Invention of the nickel-cadmium battery
1901	Edison (USA)	Invention of the nickel-iron battery
1932	Shlecht & Ackermann (Germany)	Invention of the sintered pole plate
1947	Neumann (France)	Successfully sealing the nickel-cadmium battery
Mid 1960	Union Carbide (USA)	Development of primary alkaline battery
Mid 1970		Development of valve regulated lead acid battery
1990		Commercialization nickel-metal hydride battery
1992	Kordesch (Canada)	Commercialization reusable alkaline battery
1999		Commercialization lithium-ion polymer
2001		Anticipated volume production of proton exchange membrane fuel cell



1791
Galvani observed that electricity is conducted through animal tissue (frog leg experiment).

1800
Alessandro Volta described the first electrochemical battery (voltaic pile).

1836
John Fredric Daniell developed the first battery able to produce a constant source of electricity (Daniell's cell).

1859
Gaston Planté developed the first rechargeable battery (lead acid battery).

1866
George Lionel Leclanché developed the first prototype of the modern dry cell (Leclanché's cell).

1878
Maiche designed the first air cell.

1899-1901
Waldmar Jungner (Sweden) invented the Ni/Cd battery (1899).
Edison (USA) invented the Ni/Fe battery (1901)

1940
The first button cell was developed (zinc/silver oxide cell).

1947
Neumann successfully sealed the Ni/Cd battery. His design is currently used in electronic applications

1959
Eveready commercialized the first alkaline battery developed by Lew Urry.

1970
Ni/H_2 battery was developed for satellite applications.

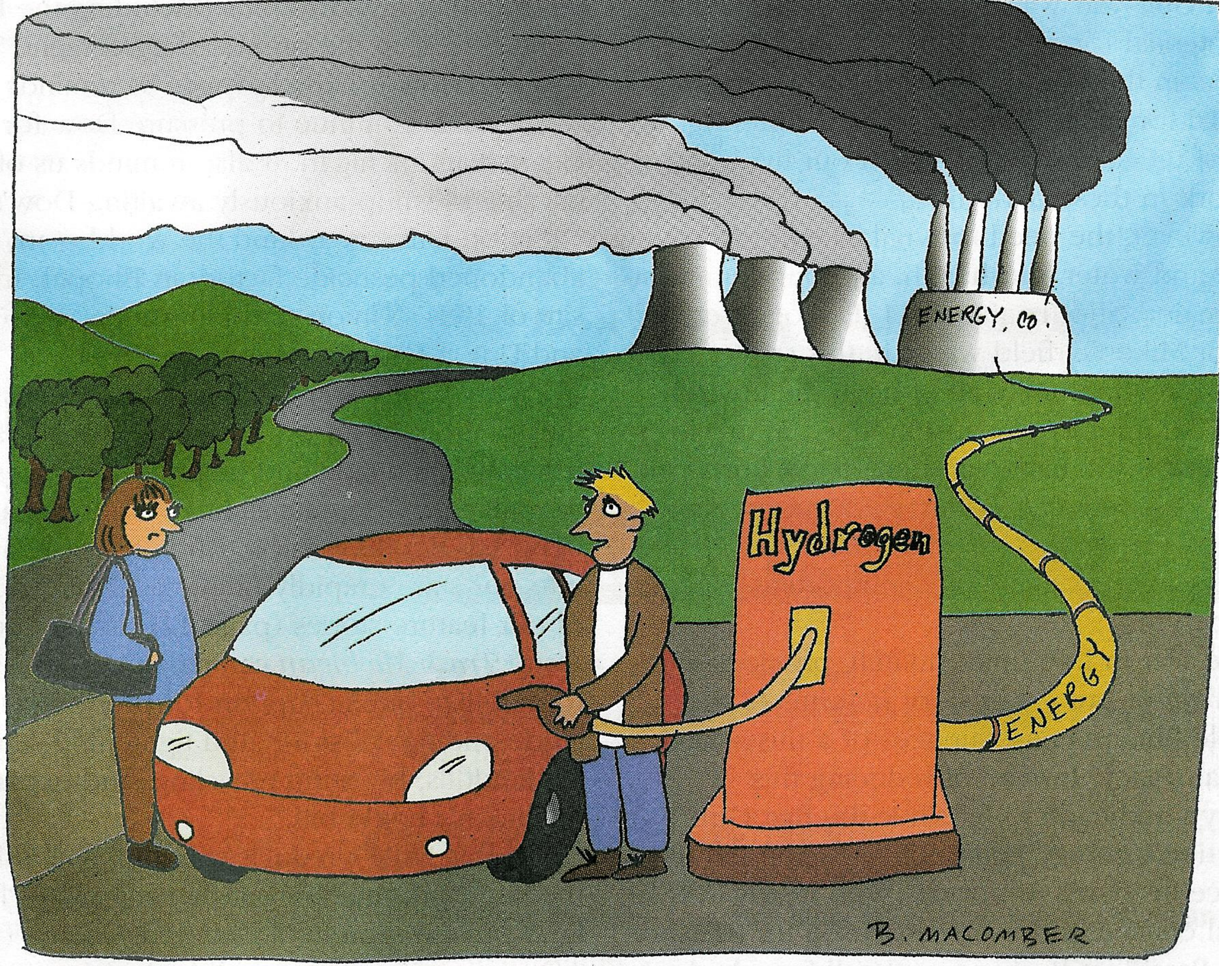
1973
SAFT introduced the first commercial primary lithium cell for military applications.

1975
Rechargeable alkaline manganese (RAM) cells were developed.

1990
Sanyo and Matsushita commercialized Ni/MH batteries

1991
Sony commercialized the first lithium ion battery.

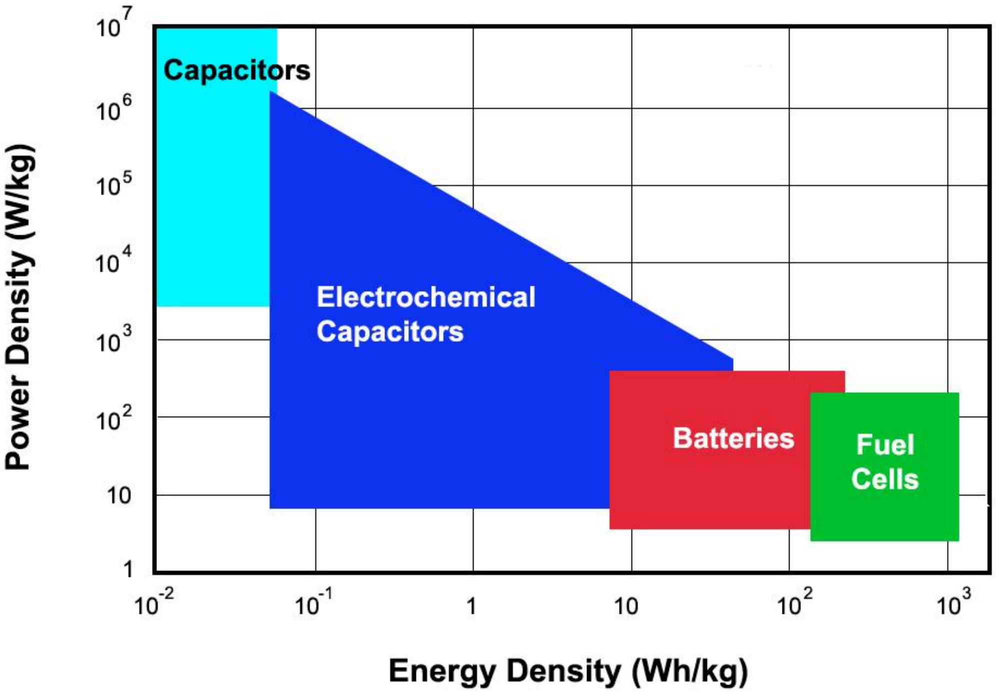
Fig. 3 Timeline for the major events in the history of batteries.


ENERGY, CO.
Hydrogen
ENERGY
B. MACOMBER

BATERÍAS

- Las baterías almacenan energía en compuestos químicos capaces de generar carga eléctrica.
- Poseen alta densidad de energía.
- Existe una gran variedad de baterías.

- Baterias Primarias (No recargables)
- Zn/carbon 1,5 V, 0,13
- Zinc/aire 1,4 V
- Zn/MnO_2 (alcalinas), 1, 5 V
- Li/$O_{2,}$ 2,91 V
- Li-$SOCl_2$, 3,5 V
- Baterias Secundarias (Recargables)
- PbO2/PbSO4, 2,1 V
- Ni/Cd, 1,2 V
- Ni/MHx (AA), 1,2 V, 1,3 Ah
- C_6Li_x/$LiCoO_2$, 3,7 V
- Li/LiFePO4, 3,3 V
- Li/$O_{2,}$ 2,91 V (futuro para vehículos)



El almacenamiento de energía es crítico para la utilización de energías renovables, para alimentar dispositivos electrónicos y para vehículos eléctricos (EV y HEV)

1.2 MW, 7.2 MWh Distributed Energy Storage System in Chemical Station, North Charleston

Started Operation on June 26th, 2006

AEP APPALACHIAN POWER
A unit of American Electric Power

NGK Insulators Ltd
S&C Electric Co.
DOE / SANDIA

Baterías de Li-ion para:

Celular 1 Ah
1 A.h 3,6 V

Laptop
4-5 A.h 11 V

Vehículo Eléctrico
100 A.h

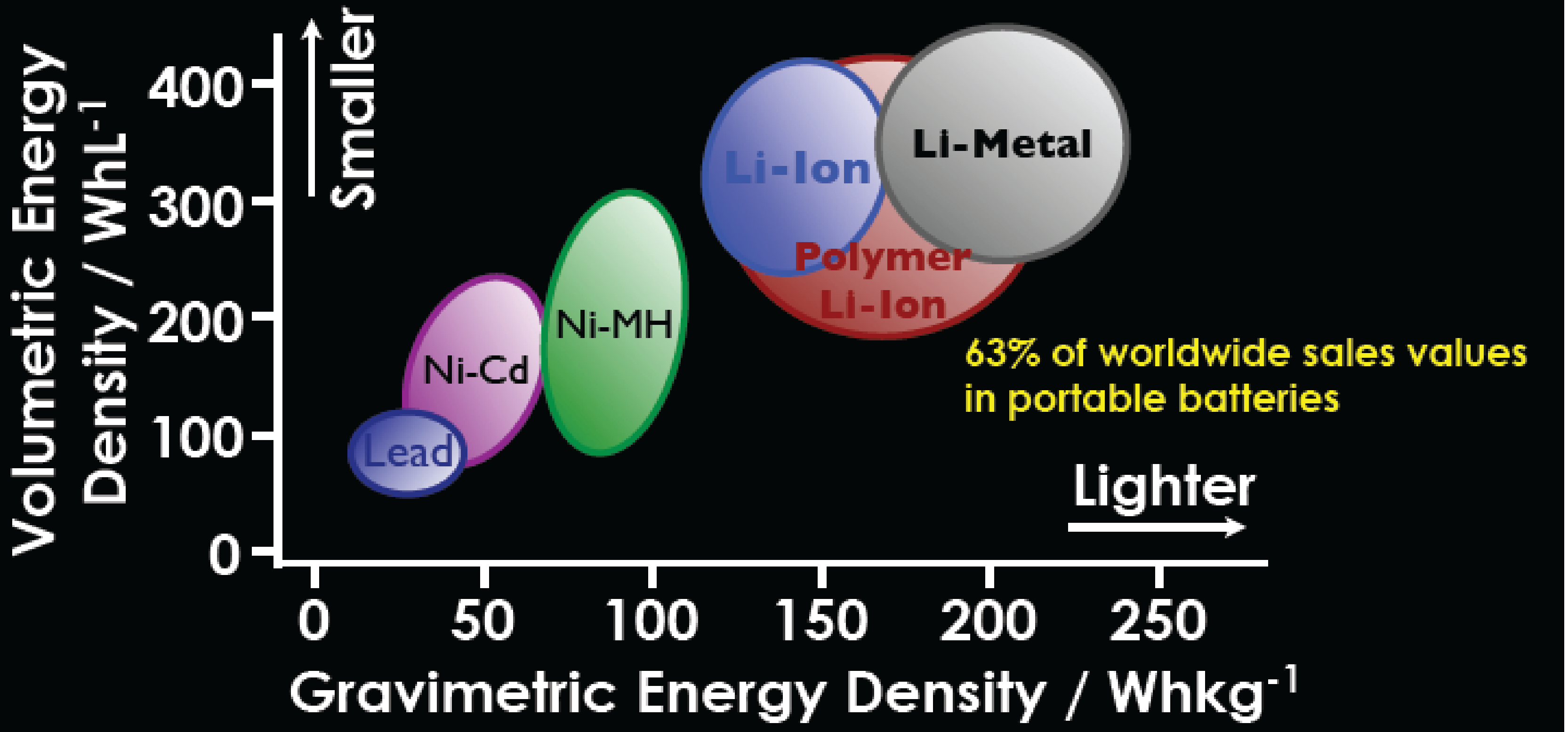
US in 1900
1500 electric cars compared with 1000 ICE cars

CANTIDADES A CONSIDERAR

- ENERGIA

  Carga x voltaje (Wh)
- CAPACIDAD

  Carga (Ah = 3600 coul)
- POTENCIA (kW)
- DENSIDAD ESPECIFICA DE ENERGIA (masa)
- (kW.h/kg)
- DENSIDAD DE ENERGIA (volumetrica)
- (kW.h/l)
- TIEMPO DE VIDA DE LA BATERIA (ciclos de carga/descarga)



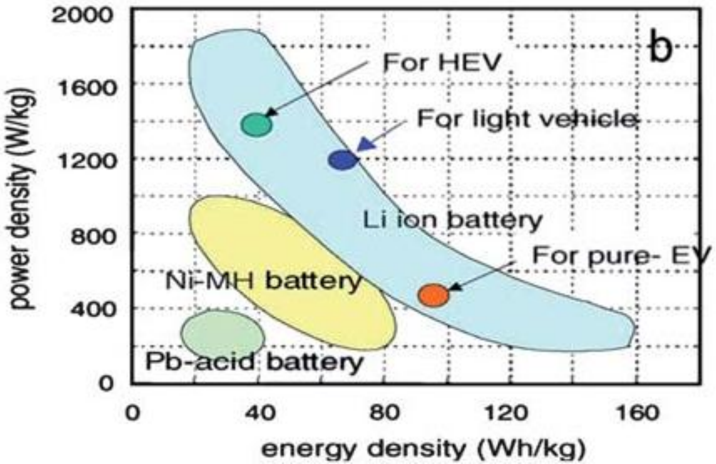
63% of worldwide sales values in portable batteries

J.-M. Tarascon & M. Armand, *Nature*, 414 359 (2001)

Tecnologias disponibles hoy

Energy & Environmental Science
Cite this: Energy Environ. Sci., 2011, 4, 3243

a Modes of operation	battery capacity needed, kWh	Energy density, Wh/kg	Weight of battery, Kg	Speed, kilometres per hour	Distance on one charge, kilometres
 Hybrid	<3	40-50 (Ni-MH)	60 (Ni-MH)	100+	15
 Plug in Hybrid	5.6-18	90-100 (Li-ion)	60-200 (Li-ion)	100+	10-60
 Full EV	35-54	90-100 (Li-ion)	450 (Li-ion)	>100	150-200



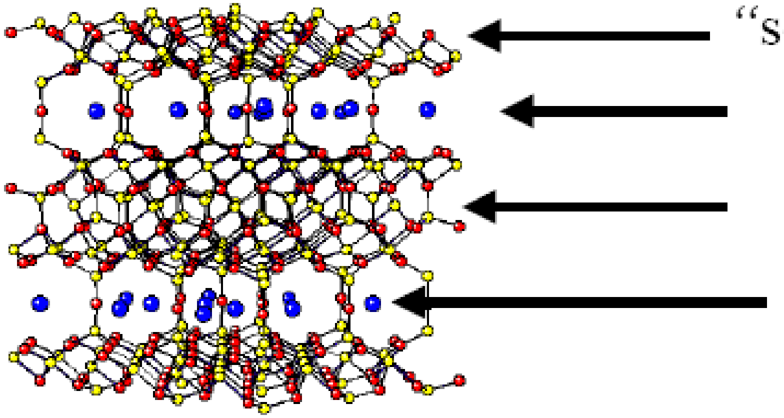
Que es electroquimica en estado solido?

1. Materiales Electroquímicos
   a. Electrolitos sólidos y poliméricos
   b. Electrodos de inserción (o intercalación)
   c. Polímeros conductores (polipirrol, polianilina, politiofeno, etc.)

2. Dispositivos Electroquímicos
   a. Baterías
   b. Celdas de Combustible de estado solido
   c. Sistemas electrocromicos, Na_xWO_3
   d. Electrodos de Referencia
   e. Sensores (sonda lambda de oxigeno)

REDES ANFITRION-HUESPED (host-guest)

Interstitial type



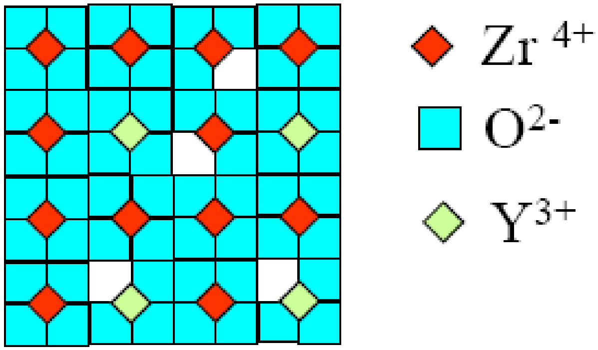
“solvent” lattice, Al_2O_3

“solute” salt, Na_2O

Immobile Al^{3+}, O^{2-}

Mobile Na^+

Vacancy type



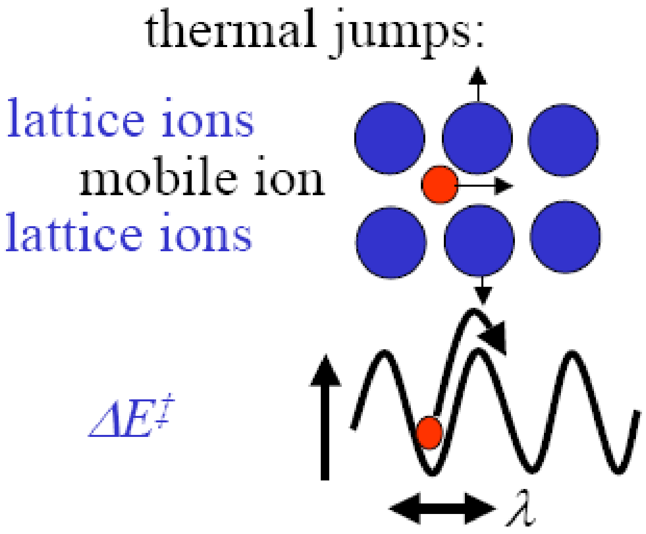
“solvent” lattice, ZrO_2

“solvent” lattice, Y_2O_3

Immobile Y^{3+}, Zr^{4+}

Mobile O^{2-} vacancies

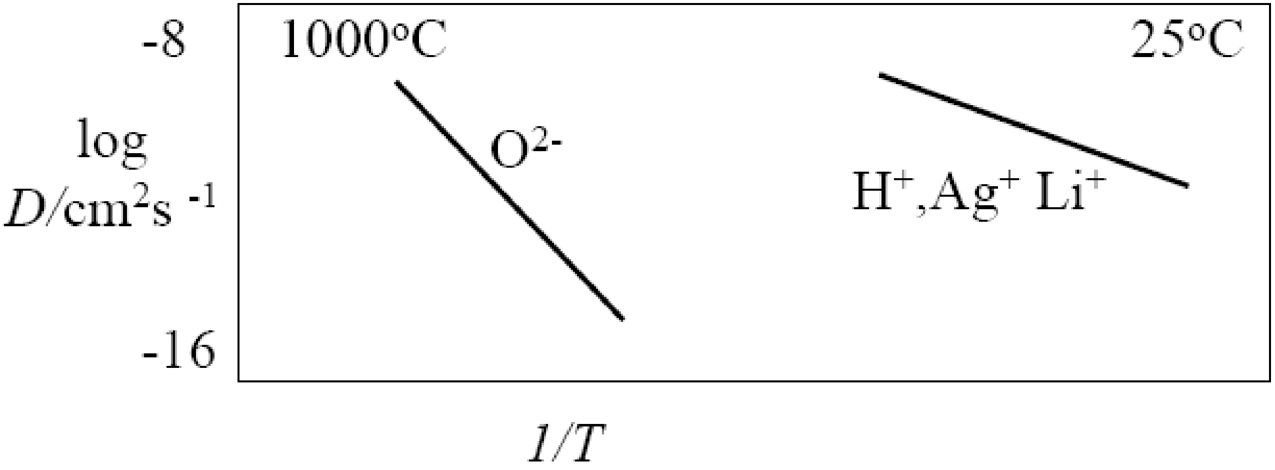
MOBILIDAD IONICA EN EL SOLIDO



Jump frequency
$\nu = \nu_o \exp(-\Delta E^{\ddagger} / kT)$

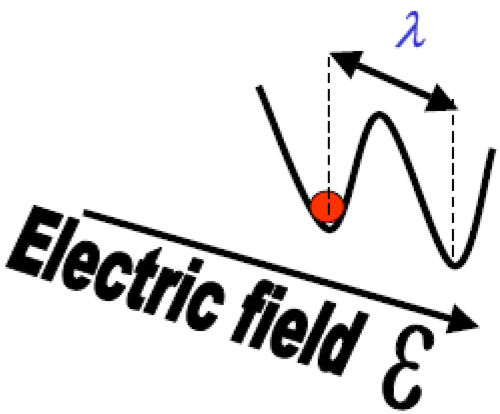
Jump distance $= \lambda$

$D \sim \nu \lambda^2$



Electrolitos sólidos

β-Al_2O_3, (Y)ZrO_2, grafito, $LiMn_2O_4$



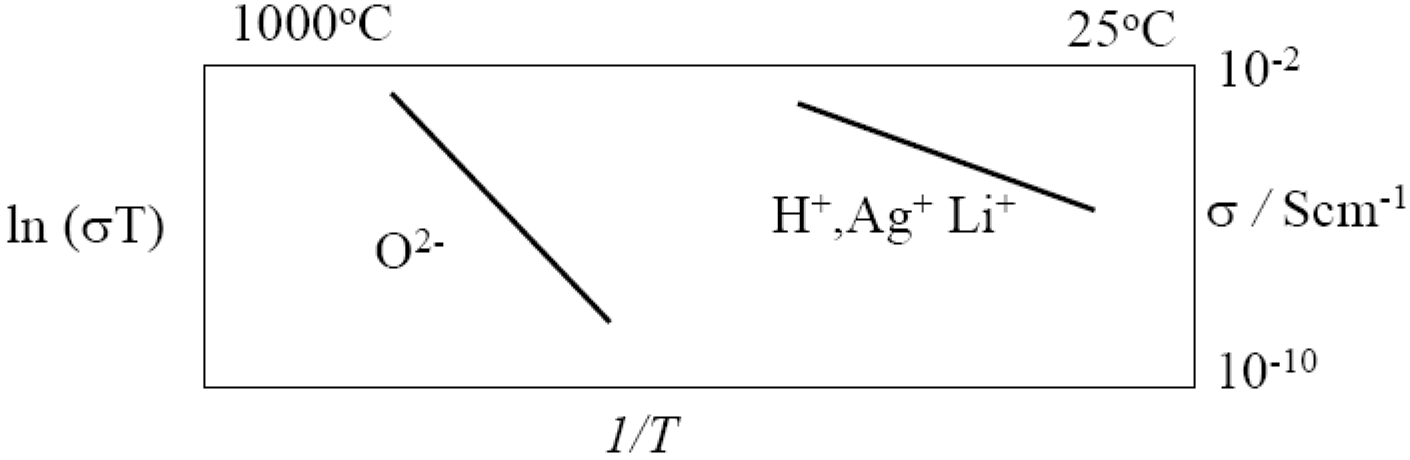
Mean velocity, $s = \lambda(\nu_R - \nu_L)$

$I = zFsc \qquad \Delta E^{\ddagger}_R = \Delta E^{\ddagger} - \lambda\,\mathcal{E}$

$\Delta E^{\ddagger}_L = \Delta E^{\ddagger} + \lambda\,\mathcal{E}$

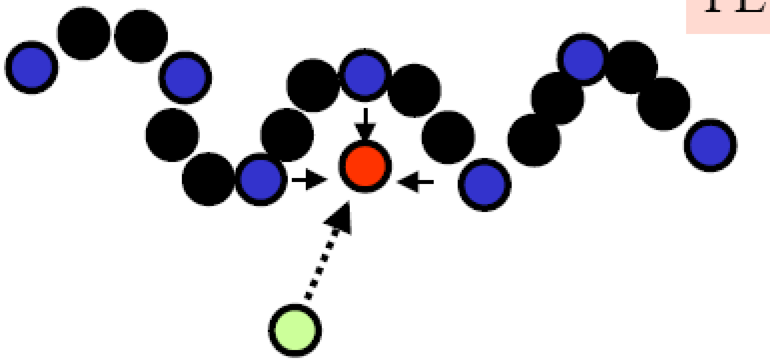
Nernst-Einstein Equation for conductivity:

$$\sigma = \{ z^2F^2/RT \}Dc$$



ELECTROLITOS POLIMERICOS

PEO, poly(ethylene oxide)

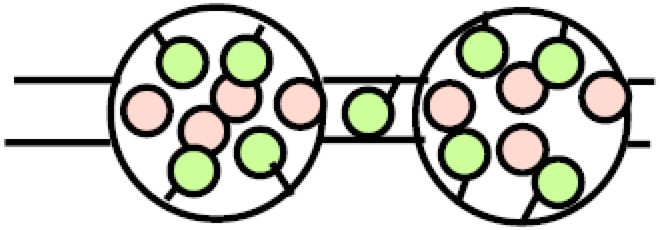


● O ● C

● Li^+ ○ X^-

(Both mobile)

Nafion



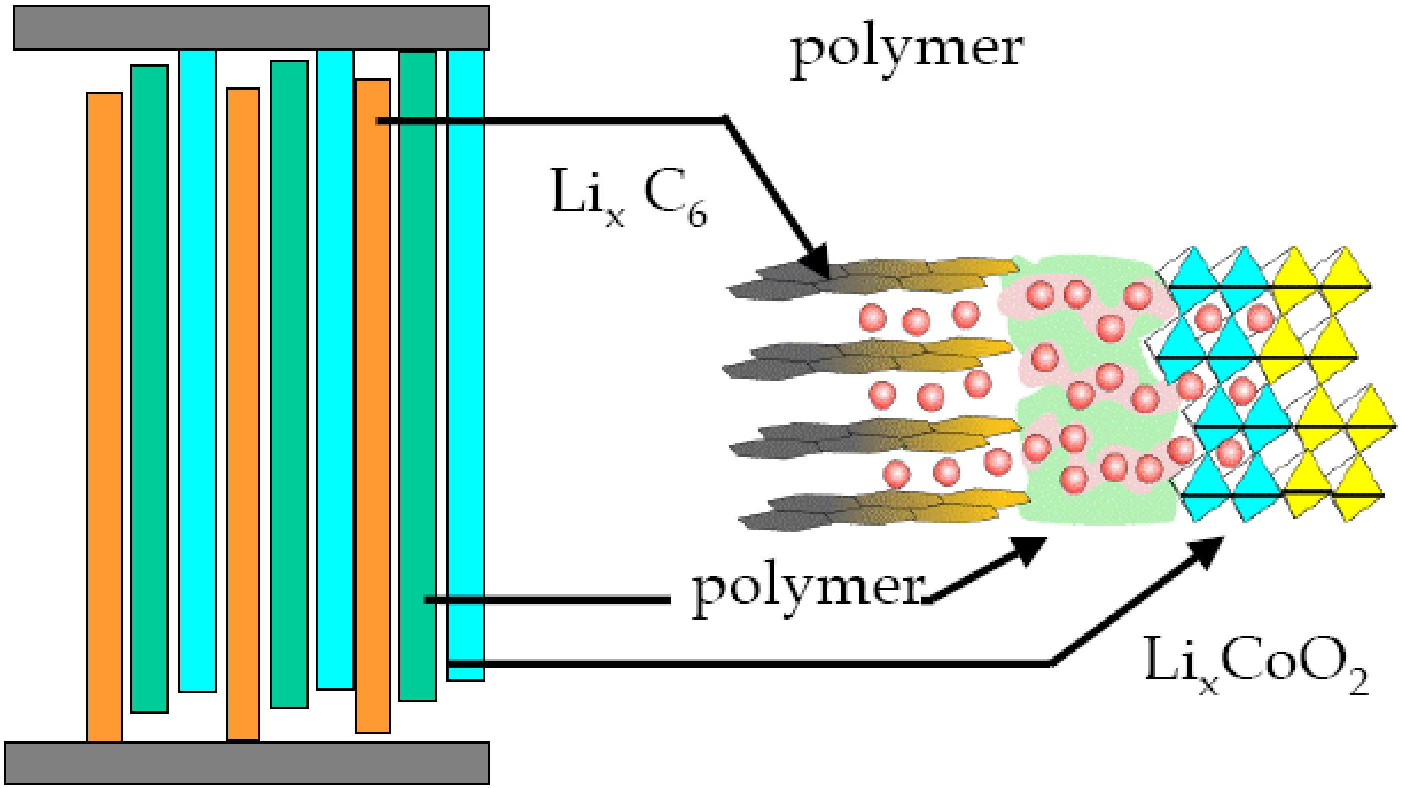
○ H_3O^+ ○ SO_3^-

Main chain $CF_2\,CF_2\,CF_2\,CF...$

side chain $(OC_2F_4)_n$

active group $OCF_2SO_3^-$

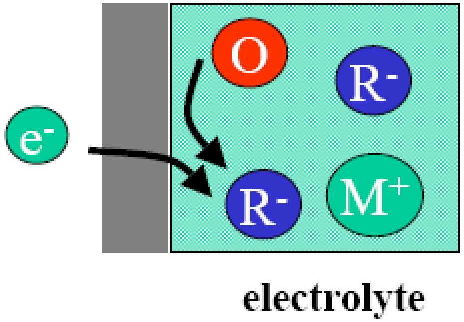
BATERIA PLASTICA DE LITIO



TRANSFERENCIA DE CARGA

Electroquimica en líquidos

$$\mathrm{ox} + n e^- \rightleftharpoons \mathrm{red}^-$$



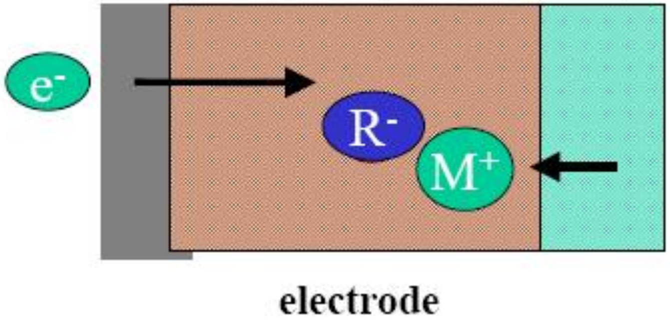
Difusión de O y R hacia y desde el electrodo

Contraiones compensan carga eléctrica

Electroquimica en sólidos

$$W^{VI}O_3 + e^- \rightleftharpoons W^{V}O_3{}^-$$

$$WO_3 + e^- + Li^+ \rightleftharpoons LiWO_3$$



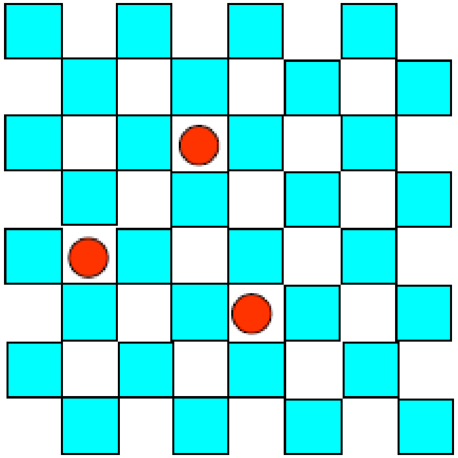
Reactivos inmóviles dentro del electrodo

La conductividad electrónica es esencial

La carga del e- requiere compensación con Li^+, H^+

El transporte iónico es determinante de la velocidad

MODELO DE RED PARA MEZCLAS



🟦 = Host structure

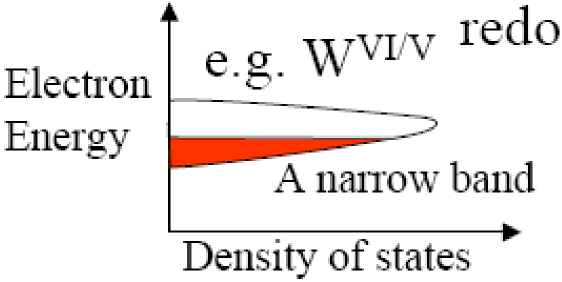
● = M^+

$$E = E_1 + (RT/F)\ln[x/(1-x)] + kx$$

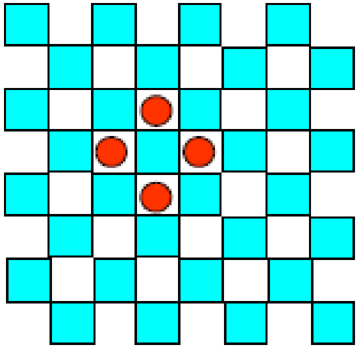
E_1 depends on redox level, e.g. $W^{VI/V}$

Entropy of a random ion distribution

Ion-ion interaction



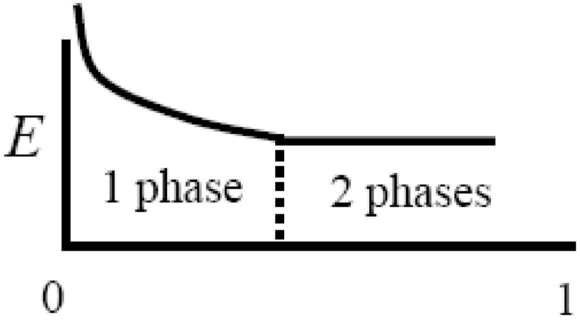
Efectos de alta concentracion del ion intercalado



Concentraciones muy altas en el solido

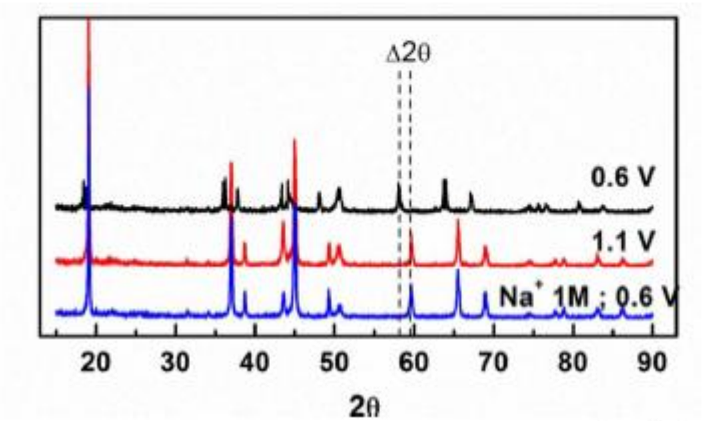
Li_xWO_3 $M = 232 + 7x$; $V_m \sim 50\ cm^3$; $[W^{VI}] \sim 20\ M$

Restricciones en sitios tetraédricos, octaédricos



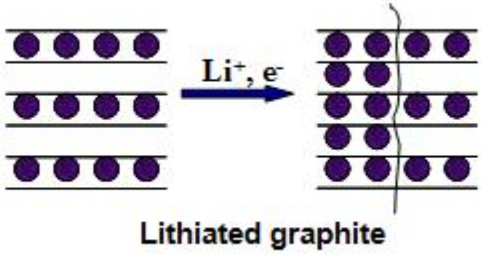
Condensacion en racimos (clusters), separacion de fases
$LiMn_2O_4$/ $Li_2Mn_2O_4$ a 3 V vs. Li/Li^+

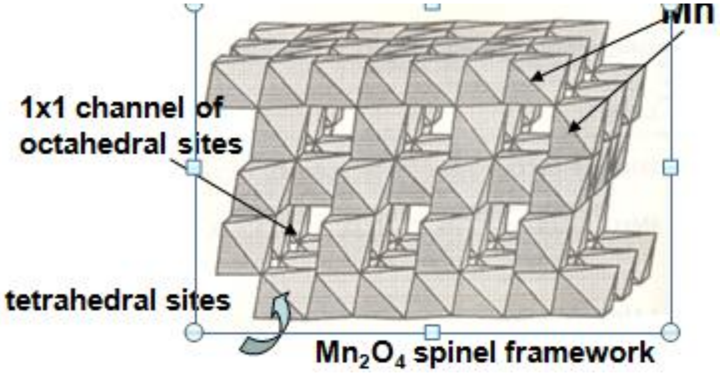
Distorsión de la red cristalina por el ion intercalado
Li^+ en oxido mixto espinela $Li_xMn_2O_4$



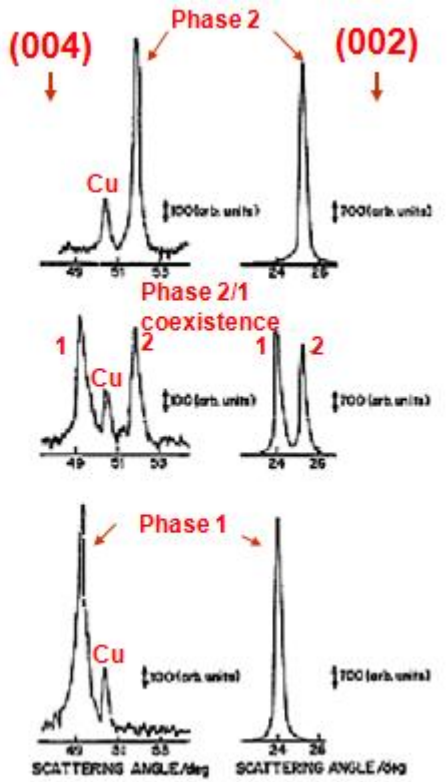
Nucleacion y crecimiento de una nueva fase

INTERCALACION DE IONES LITIO EN GRAFITO y OXIDOS





ESTUDIO DEL DIAGRAMA DE FASES DE LiCx POR DRX



EN RESUMEN

La electroquímica de estado sólido depende de la mobilidad iónica

El coeficiente de difusión depende de la estructura del sólido

La conductividad de electrolitos sóidos depende de la estructura

Los electrodos de intercalación o inserción involucran reacciones redox con mobilidad electrónica

La relación potencial redox-composición depende de la estructura del sólido

Pouch Cell

18650

Cilíndrica

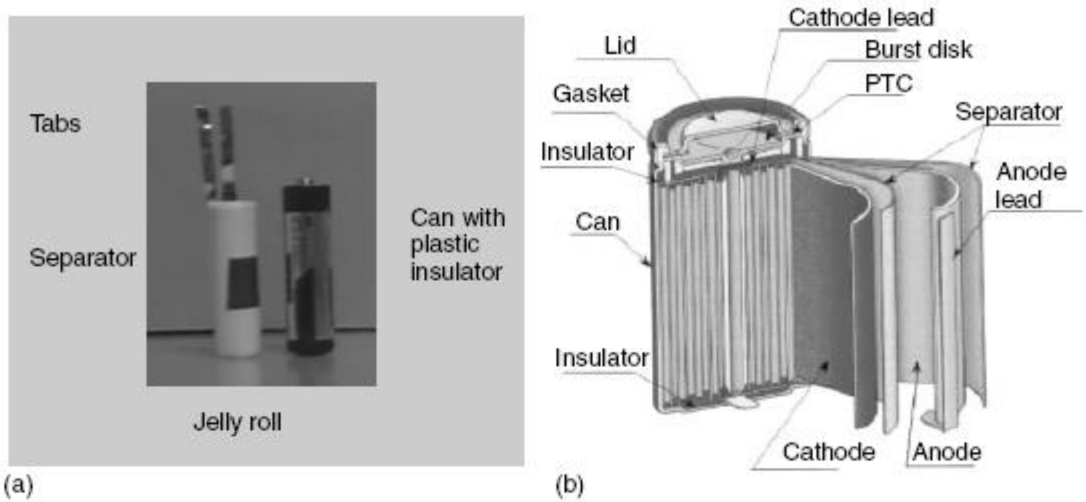
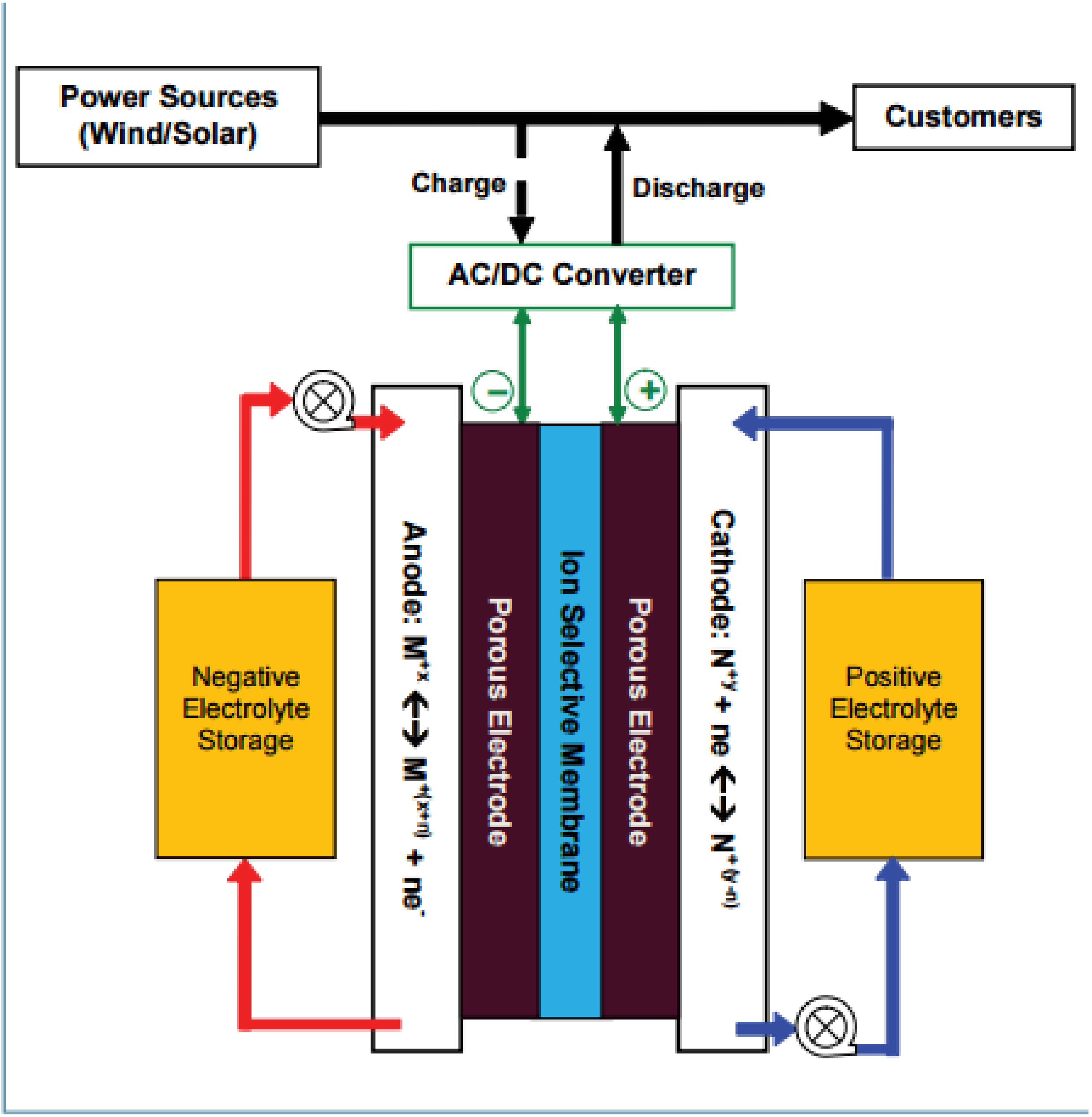


Fig. 2 Schematic diagram of a complete lithium-ion battery. (a) Jelly roll, (b) other components and safety devices (from Ref. 5).


Power Sources (Wind/Solar)
Customers
Charge
Discharge
AC/DC Converter
−
+
Negative Electrolyte Storage
Anode: $M^{+x} \leftrightarrow M^{+(x+n)} + ne^-$
Porous Electrode
Ion Selective Membrane
Porous Electrode
Cathode: $N^{+y} + ne \leftrightarrow N^{+(y-n)}$
Positive Electrolyte Storage

Celdas redox de Flujo

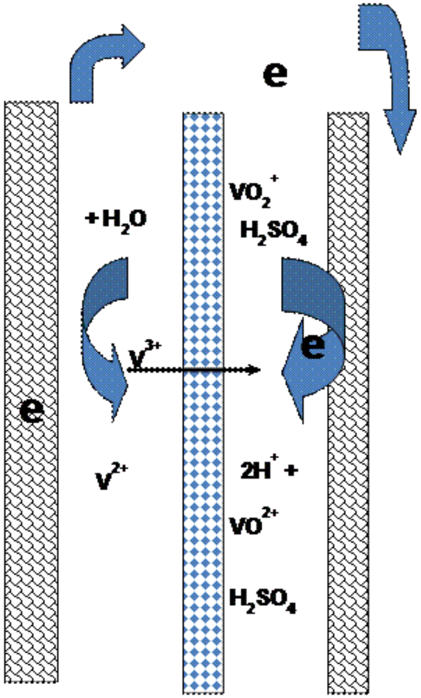


Fig. 5. Schematics representing the electrochemical reactions in the all vanadium redox battery.

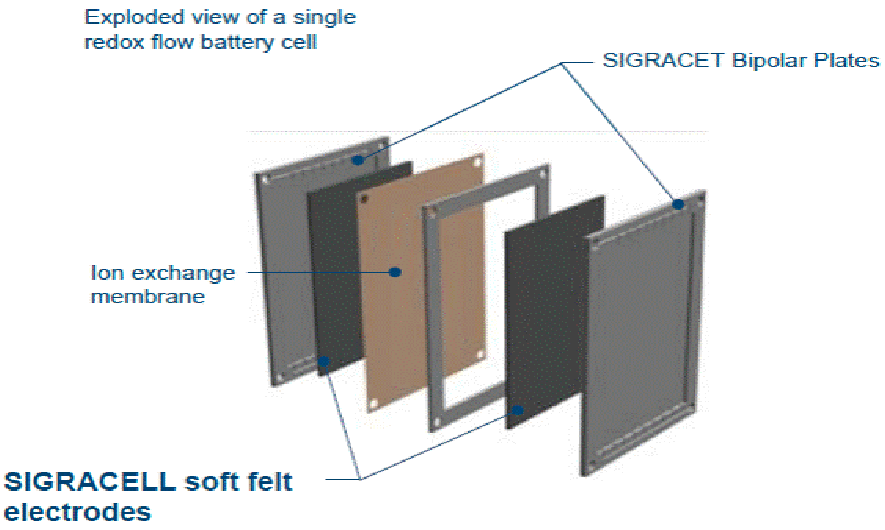
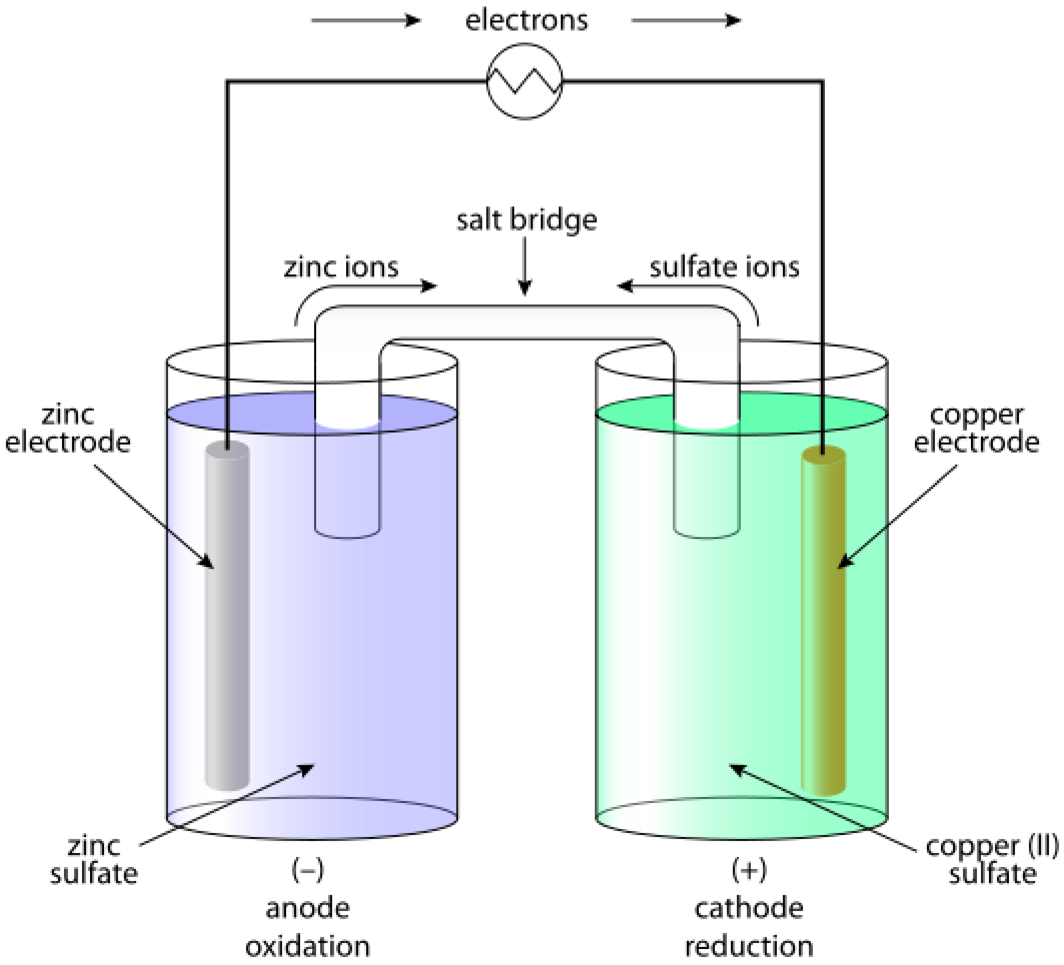


Fig. 3. An exploded view of a single redox flow-battery cell.

BATERIA DE DANIEL 1836



LECLANCHE (1868)

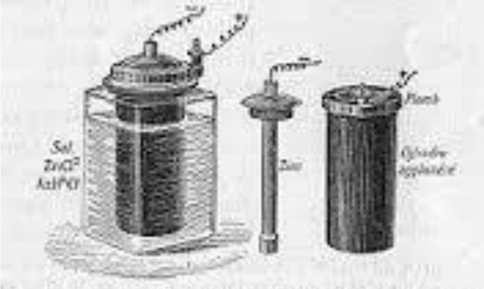
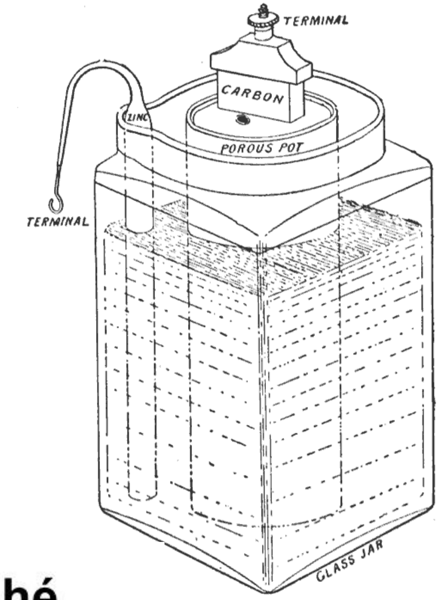
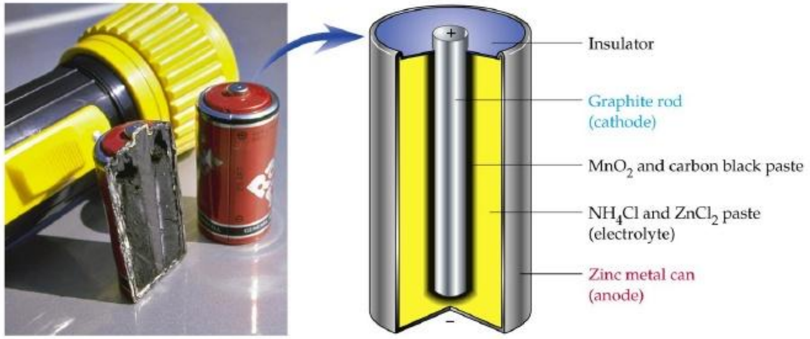


Fig. 990. — Élément Leclanché-Barbier.

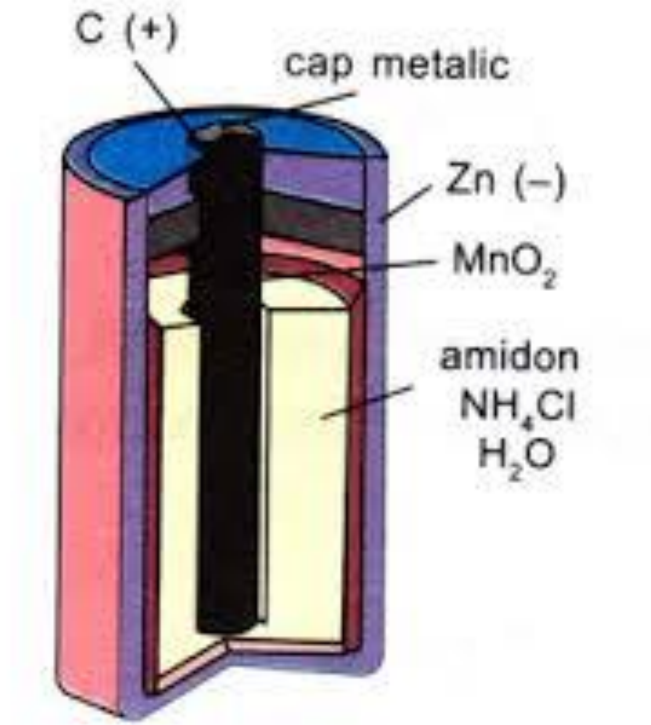


Leclanche humeda

Pila seca o pila de Leclanché



Zn + 2 MnO2 +NH4Cl--------→ZnCl2 + Mn2O3 +NH3 + H2O



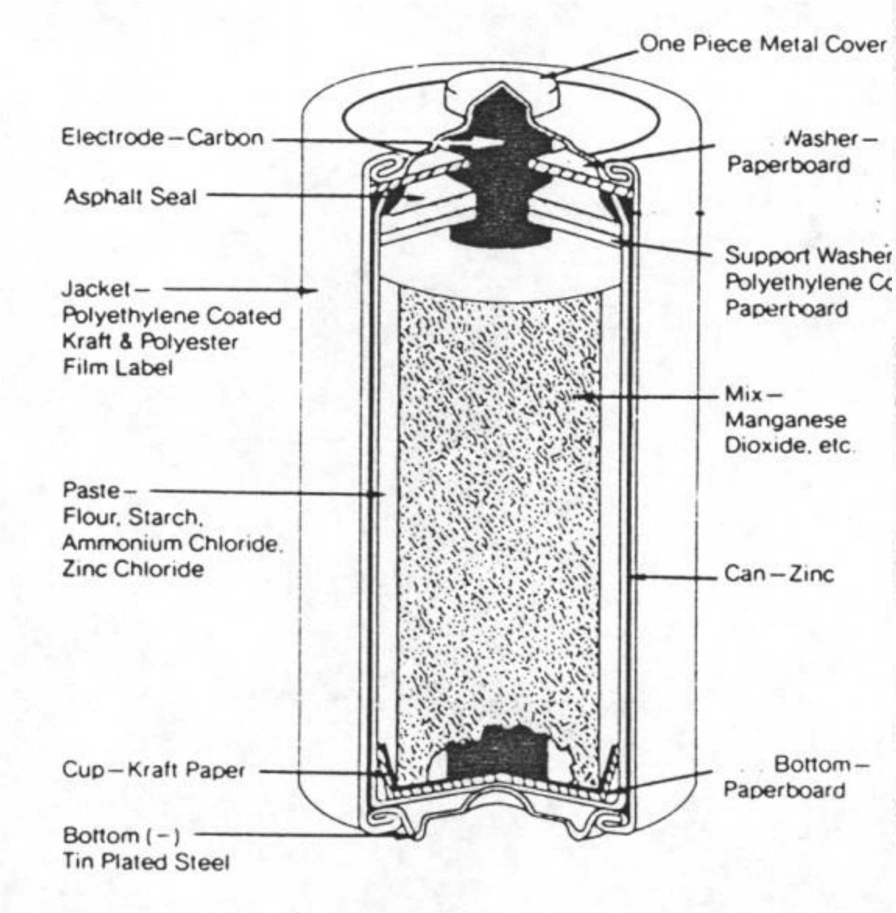
Pila Leclanche

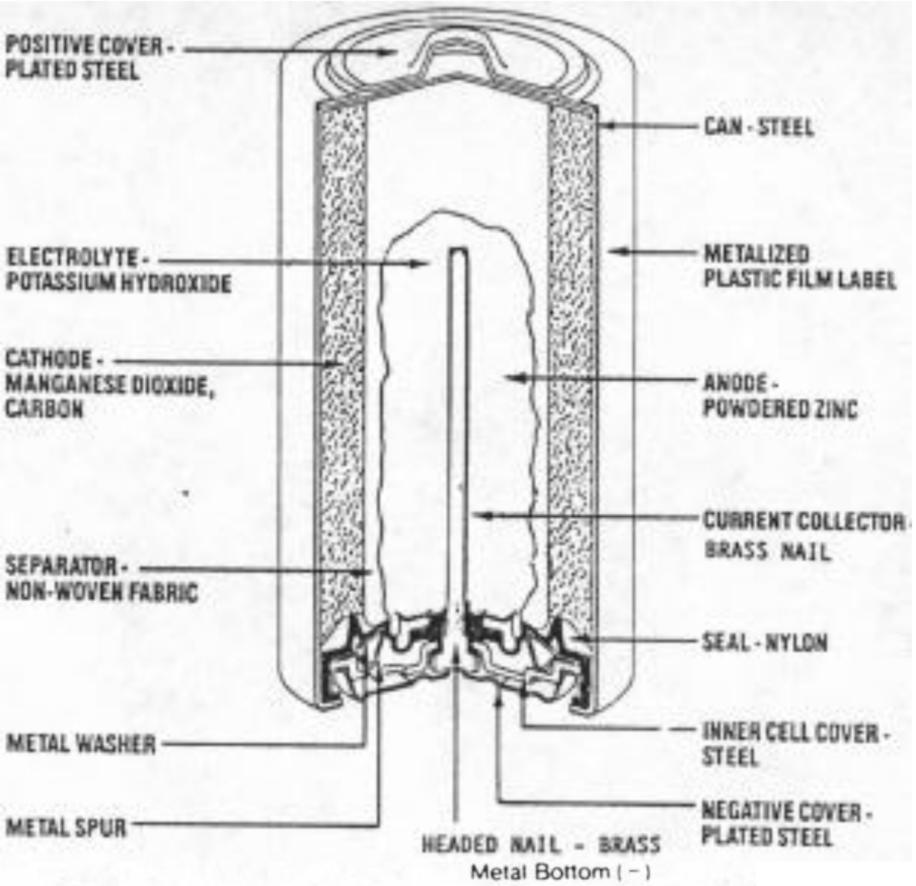
Baterías primarias

En estas celdas las reacciones en los electrodos son irreversibles

Pila Leclanche (Zn/MnO_2)

Pila alcalina





A: $Zn \longrightarrow Zn^{2+} + 2e$ $Zn + 2\,OH^- \longrightarrow ZnO + H_2O + 2e$

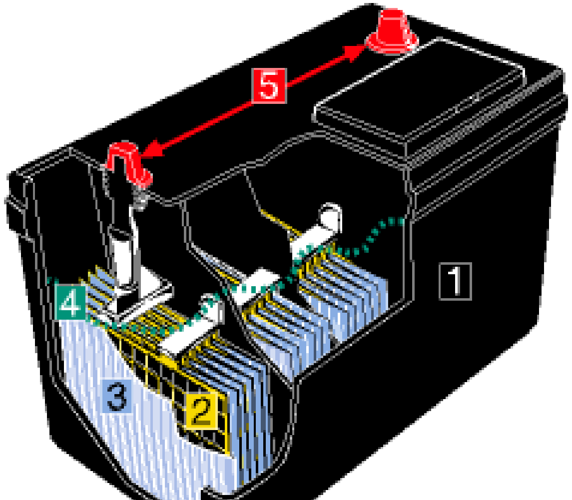
C: $2MnO_2 + 2H^+ + 2e \longrightarrow 2MnOOH$ $2MnO_2 + H_2O + 2e \longrightarrow Mn_2O_3 + 2\,OH^-$

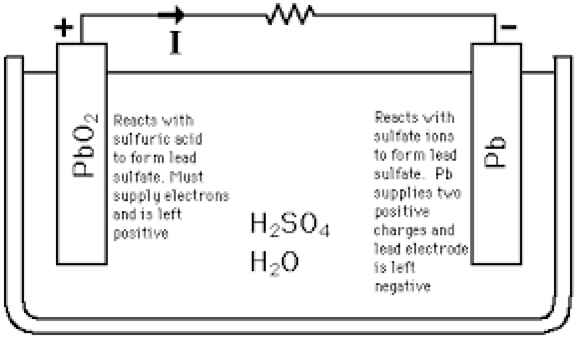
Acumulador de Plomo-Acido (Plante 1859)

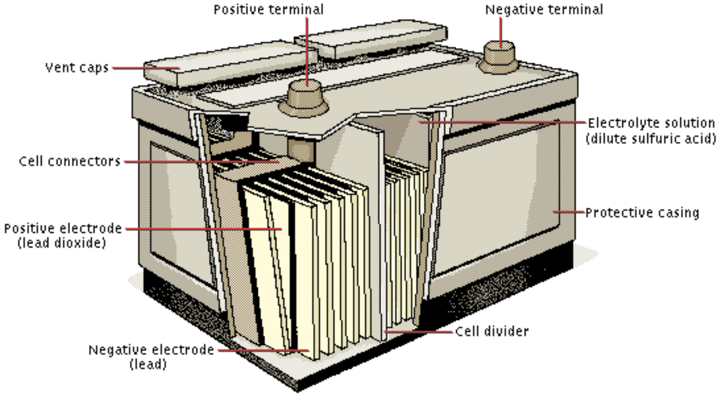
$$PbO_2 + Pb + 2H_2SO_4 = 2PbSO_4 + 2H_2O$$

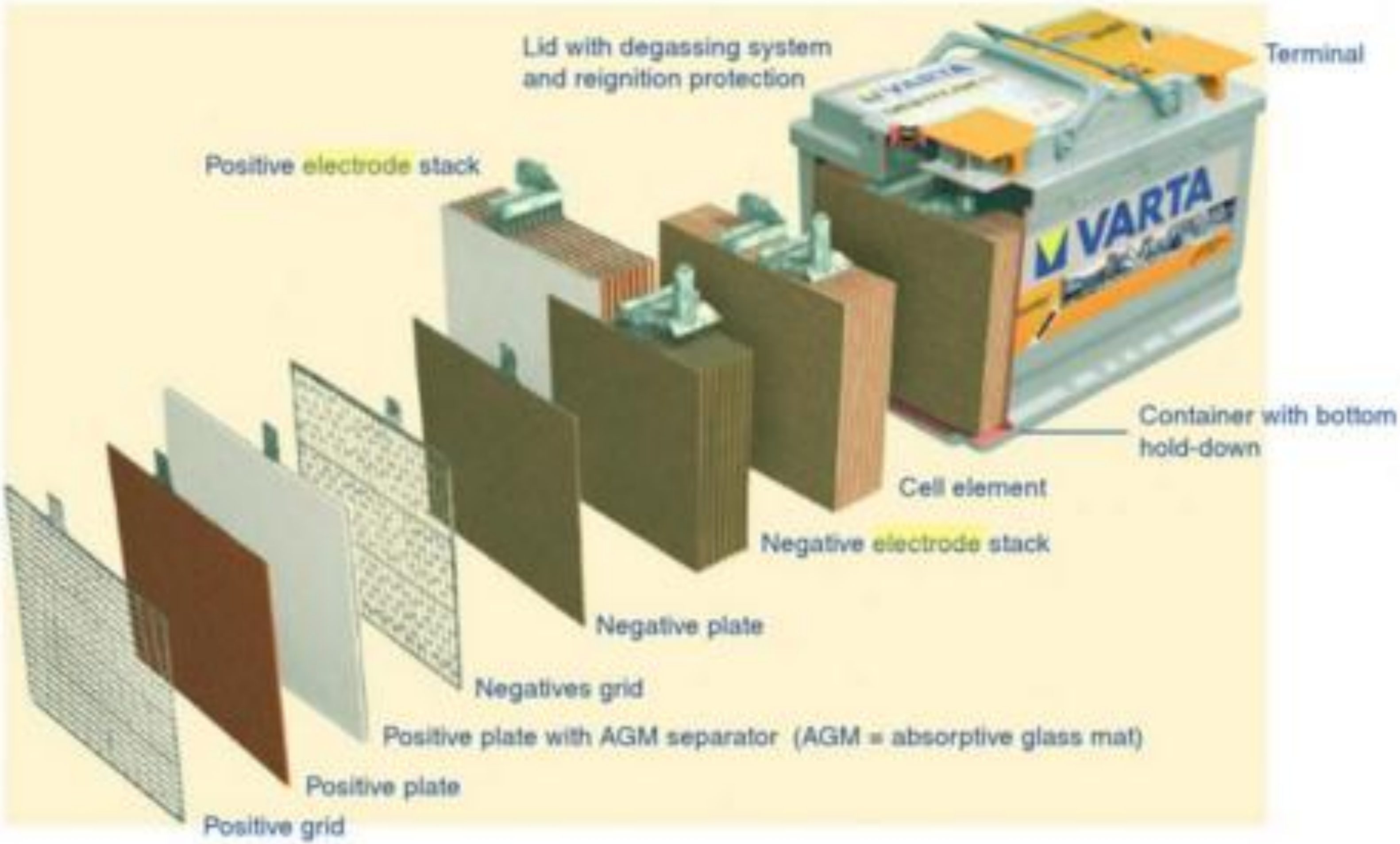
$$PbO_2 + 3H^+ + HSO_4^- + 2e \rightleftarrows PbSO_4 + 2H_2O$$

$$Pb + HSO_4^- = PbSO_4 + H^+ + 2e$$





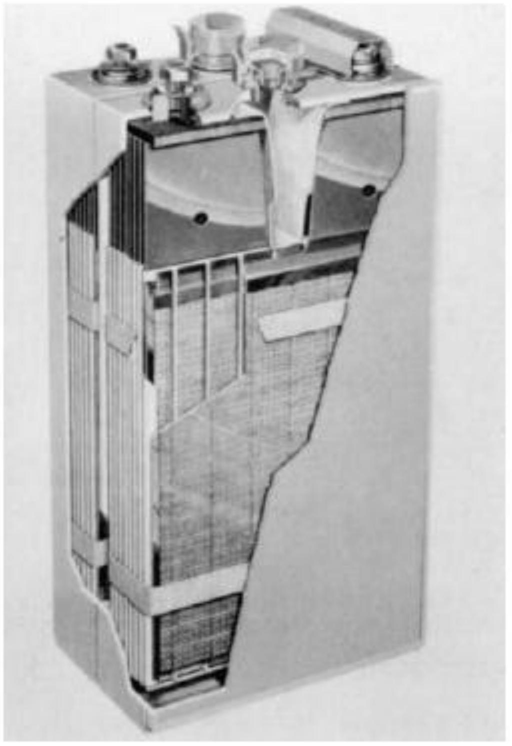



Lid with degassing system and reignition protection
Terminal
Positive electrode stack
VARTA
Container with bottom hold-down
Cell element
Negative electrode stack
Negative plate
Negatives grid
Positive plate with AGM separator (AGM = absorptive glass mat)
Positive plate
Positive grid

Batería de Niquel-Cadmio (1899)

(-) Ánodo

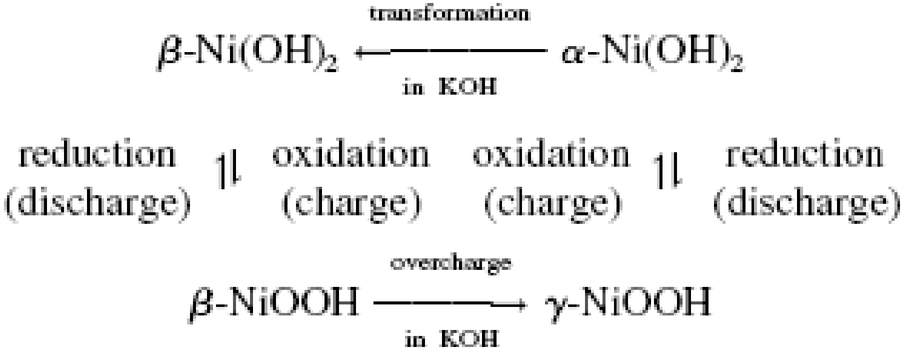
$$\beta-NiOOH + H_2O + e \longrightarrow HO^- + \beta-Ni(OH)_2$$



(+) Cátodo

$$Cd + 2HO^- \longrightarrow Cd(OH)_2 + 2e$$

1.35 V 181 Ah/g



$$\begin{tikzcd}
\beta\text{-Ni(OH)}_2 \arrow[d, shift left, "\text{oxidation (charge)}"] & \alpha\text{-Ni(OH)}_2 \arrow[l, "\text{transformation}"', "\text{in KOH}"] \arrow[d, shift right, "\text{oxidation (charge)}"'] \\
\beta\text{-NiOOH} \arrow[u, shift left, "\text{reduction (discharge)}"] \arrow[r, "\text{overcharge}", "\text{in KOH}"'] & \gamma\text{-NiOOH} \arrow[u, shift right, "\text{reduction (discharge)}"']
\end{tikzcd}$$

γ-NiOOH/β-NiOOH resulta en 15% de variación de volumen en NiOOH/$Ni(OH)_2$

Batería de Hierro-Níquel (1901)

$$Fe + 2NiOOH + 2H_2O \rightleftarrows 2Ni(OH)_2 + Fe(OH)_2$$

$$3Fe(OH)_2 + 2NiOOH \rightleftarrows 2Ni(OH)_2 + Fe_3O_4 + 2H_2O$$

$$Fe + nOH^- \rightarrow FE(OH)_n^{2-n} + 2e \qquad \text{(first plateau)}$$

$$Fe(OH)_n^{2-n} \rightarrow Fe(OH)_2 + nOH^-$$

$$Fe(OH)_2 + OH^- \rightarrow Fe(OH)_3 + e \qquad \text{(second plateau)}$$

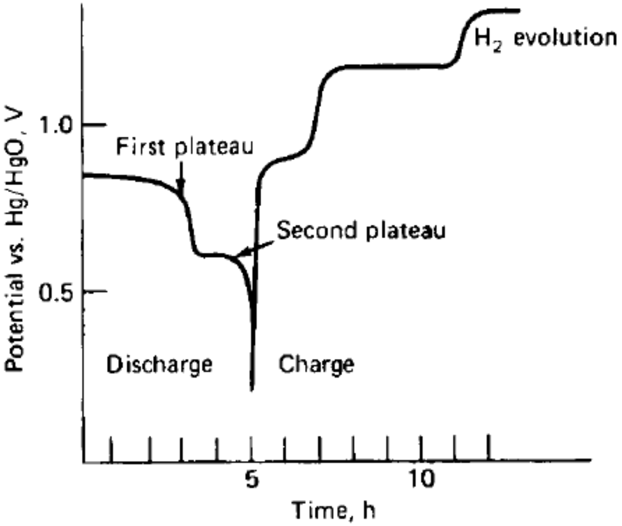


FIGURE 25.1 Discharge-charge curve of an iron electrode. (*From Ref. 5.*)

$$2Fe(OH)_3 + Fe(OH)_2 \rightarrow Fe_3O_4 + 4H_2O$$

Reaccion Global $$3Fe + 8NiOOH \rightleftarrows 8Ni(OH)_2 + Fe_3O_4 + 2H_2O$$

1,4 V 224 Ah/g

Batería Metal-Hidruro

Anodo

$$\mathbf{2MH \rightleftharpoons 2M + H_2}$$

$$\mathbf{H_2O + M + e^- \rightleftharpoons OH^- + MH}$$

$$E_1 = -0{,}06pH - 0{,}03P_{H_2}$$

Cátodo

$$\mathbf{NiOO + H_2O + e \rightleftharpoons Ni(OH)_2 + HO^-}$$

$$E_2 = E_2^0 + \frac{RT}{F} ln\left[\frac{Ni^{III}}{Ni^{II}}\right] - \frac{RT}{F} ln(HO^-)$$

$$\Delta E = E_2 - E_1 = E_2^0 + \frac{RT}{F} ln\left[\frac{Ni^{III}}{Ni^{II}}\right] - \frac{RT}{2F} P_{H_2} = -\frac{\Delta G}{F}$$

$$E_2^0 = 1{,}35\ V\ a\ 25^\circ C$$

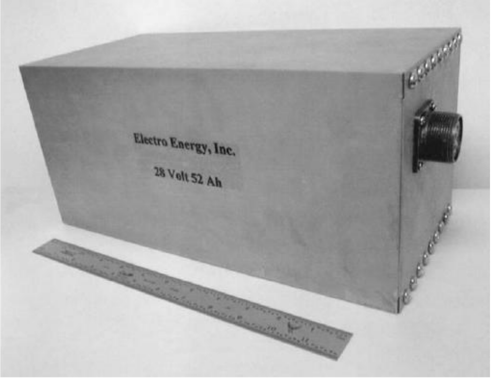


FIGURE 30.19 28 V, 52 Ah NiMH LEO Satellite Battery. (*Courtesy Electro-Energy Inc.*)

Reacción global

$$NiOOH + MH = Ni(OH)_2 + M$$

$$4MH + O_2 \rightarrow 4M + 2H_2O$$

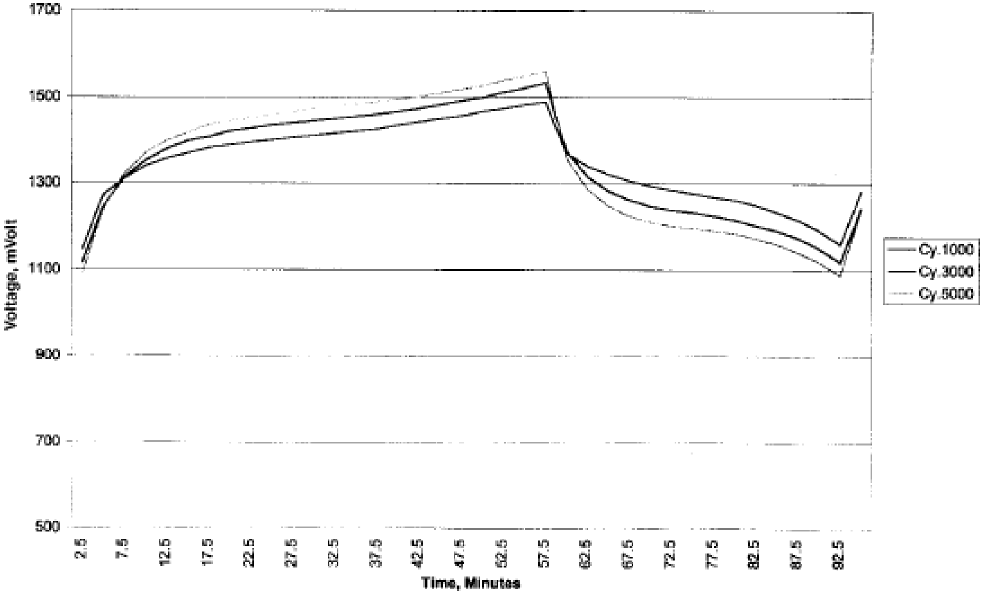


FIGURE 30.20 Cycle life of a single sealed 1.6 Ah single-cell battery operated at 40% DOD, 55 Minutes Charge at 0.72 Amp. and 35 minute discharge at 1.1 Amp. (*Courtesy Electro-Energy Inc.*)

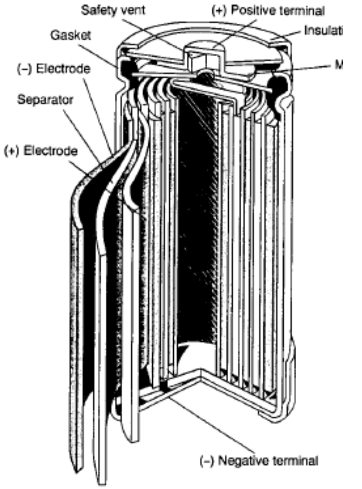


FIGURE 29.2*a* Construction of a sealed cylindrical nickel-metal hydride battery. (*Courtesy of Duracell, Inc.*)

1,35 V
178 Ah/g

BATERIA NIQUEL-CINC

Discharge		$E°$
Positive electrode	$2\ NiOOH + 2\ H_2O + 2\ e^- \rightarrow 2\ Ni(OH)_2 + 2\ OH^-$	0.49 V
Negative electrode	$Zn + 2\ OH^- \rightarrow Zn(OH)_2 + 2\ e^-$	1.24 V
Overall reaction	$2\ NiOOH + 2\ H_2O + Zn \rightarrow 2\ Ni(OH)_2 + Zn(OH)_2$	1.73 V
Charge		
Overall Reaction	$2\ Ni(OH)_2 + Zn(OH)_2 \rightarrow 2\ NiOOH + 2\ H_2O + Zn$	
Overcharge		
Positive electrode	$2\ OH^- \rightarrow \frac{1}{2}\ O_2 + H_2O + 2\ e^-$	
Negative electrode	$2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$	
	$Zn + \frac{1}{2}\ O_2 \rightarrow ZnO$ *(Recombination of oxygen from the positive electrode)*	
Overall reaction	$H_2O \rightarrow H_2 + \frac{1}{2}\ O_2$	

FIGURE 31.20 Nickel-zinc powered ZAP electric bicycle. (*Courtesy of Evercel Corp.*)

31-35% KOH, 1% LiOH 1,73 V 215 Ah/g

TABLE 31.2 Characteristics of Nickel-Zinc Batteries

Parameter	Nickel-zinc
Cathode electrochemistry	$Ni(OH)_2/NiOOH$
Anode electrochemistry	ZnO/Zn
Theoretical specific energy (Watt-hours per kilogram)	334
Electrolyte (% potassium hydroxide)	20 to 25
Nominal cell voltage (Volts)	1.65
Operating temperature range (°C)	–20 to 50
Specific energy (Watt-hours per kilogram)	50–60
Energy density (Watt-hours per liter)	80–120
Specific power (Watts per kilogram)	280
Power density (Watts per liter)	420
Charge retention (percent loss per month @ 25°C)	<20
Cycle life (cycles @ 100% DOD)	~500

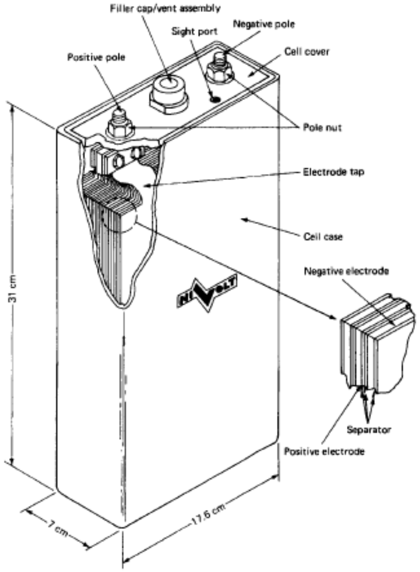
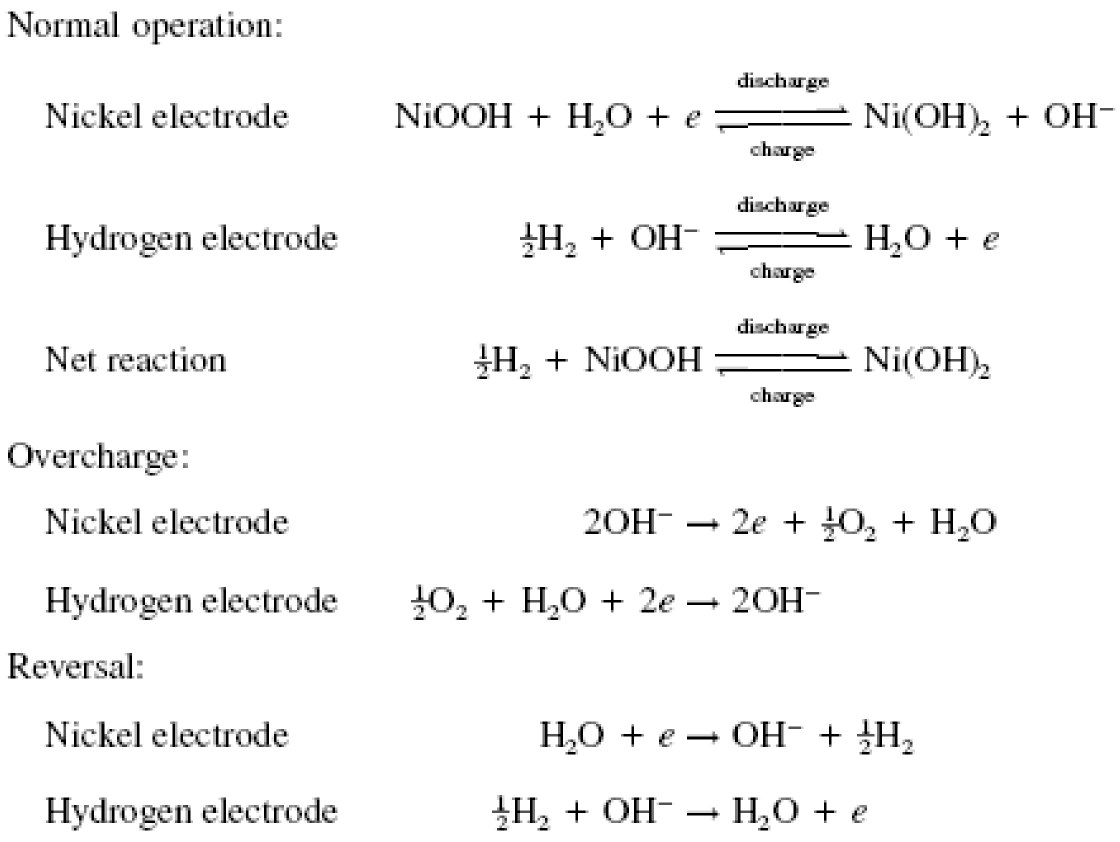


FIGURE 31.7 Sealed nickel-zinc cell. (*Courtesy of Evercel Corp.*)

Bateria Recargable de Ni-H_2

1.55 V 289 Ah/g 26% KOH 15 años de vida útil A 80% DOD



Normal operation:

Nickel electrode	$NiOOH + H_2O + e \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} Ni(OH)_2 + OH^-$
Hydrogen electrode	$\frac{1}{2}H_2 + OH^- \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} H_2O + e$
Net reaction	$\frac{1}{2}H_2 + NiOOH \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} Ni(OH)_2$

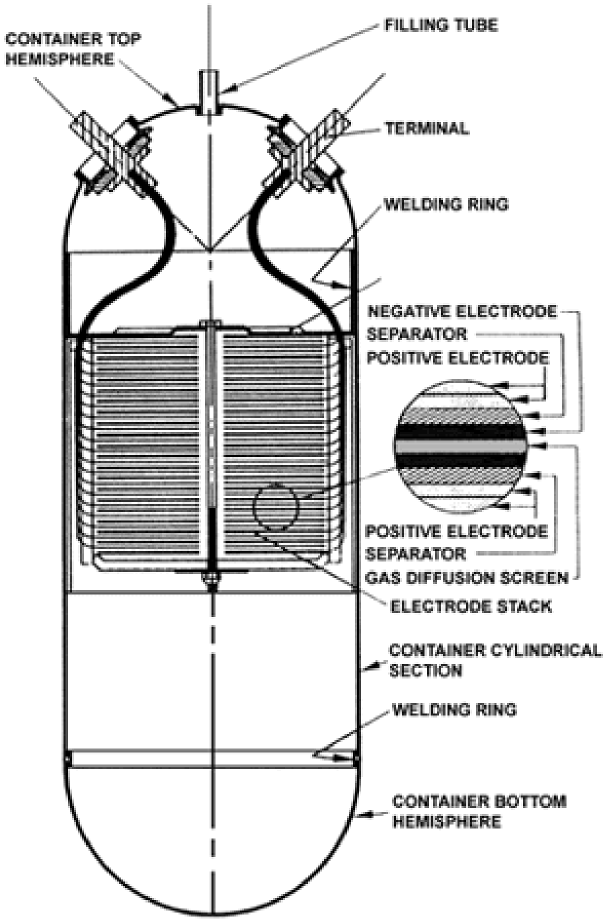
Overcharge:

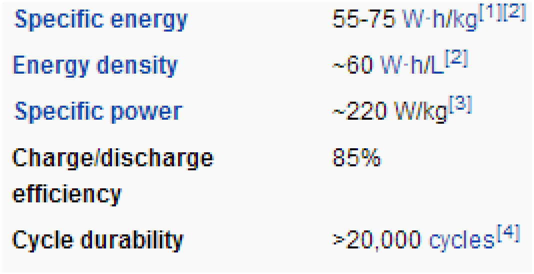
Nickel electrode	$2OH^- \rightarrow 2e + \frac{1}{2}O_2 + H_2O$
Hydrogen electrode	$\frac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^-$

Reversal:

Nickel electrode	$H_2O + e \rightarrow OH^- + \frac{1}{2}H_2$
Hydrogen electrode	$\frac{1}{2}H_2 + OH^- \rightarrow H_2O + e$

Batería Ni-H_2 para uso espacial COMSAT presurizada a 82 bar de H_2





Specific energy	55-75 W·h/kg[1][2]
Energy density	~60 W·h/L[2]
Specific power	~220 W/kg[3]
Charge/discharge efficiency	85%
Cycle durability	>20,000 cycles[4]

Híbrido bateria-celda de combustible

FIGURE 32.8 International Space Station 81-Ah Ni-H_2 38-cell assembly.

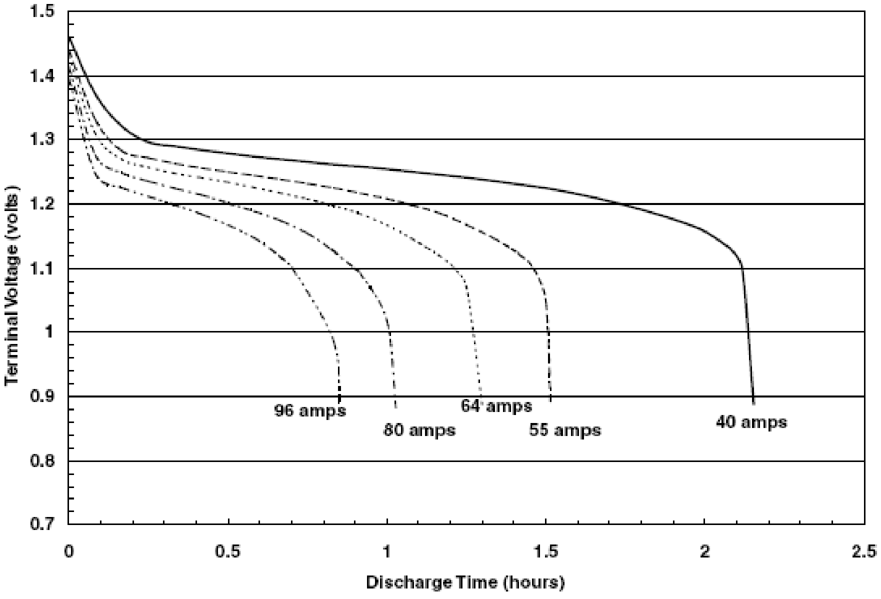
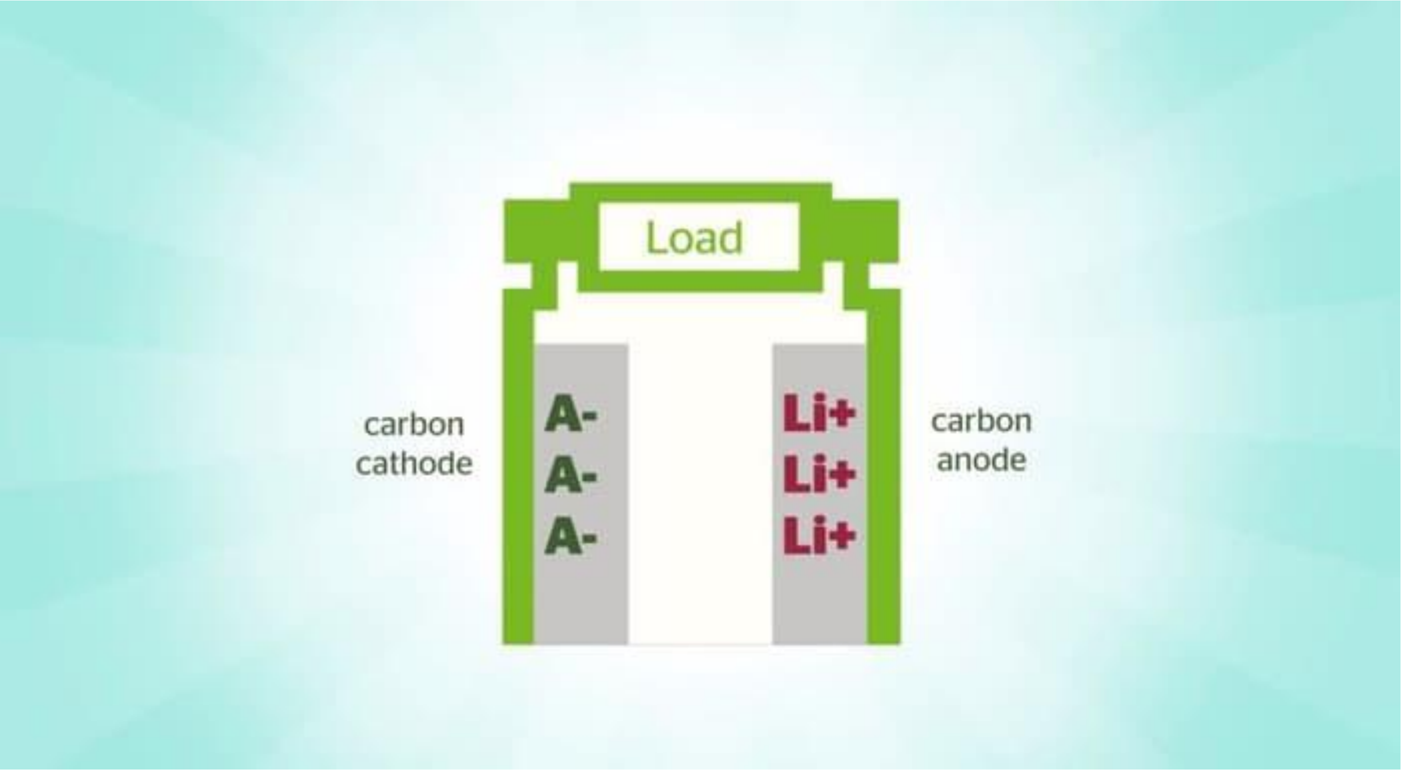


FIGURE 32.20 Discharge of Hubble Space Telescope cell at different rates.

DUAL CARBON BATTERY

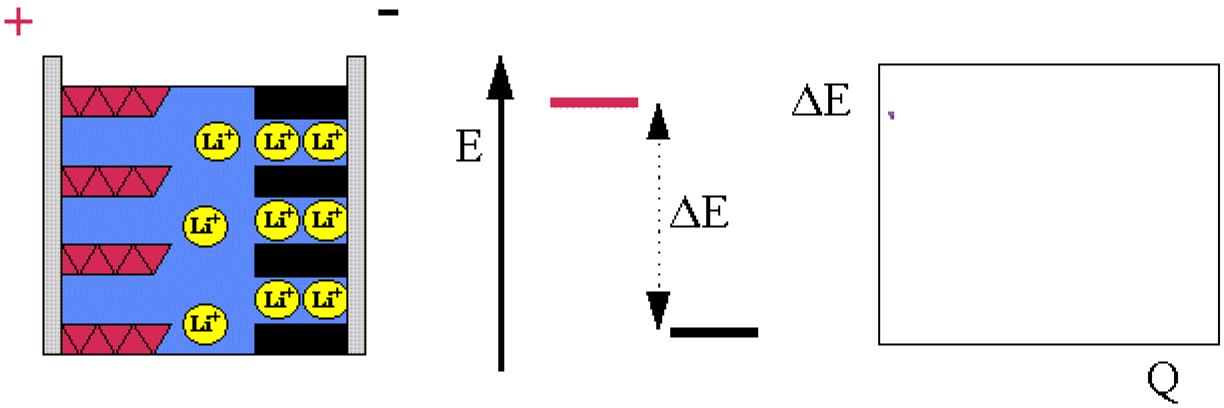


An example: Li^+ ion batteries

All reactions occur at the interface
Whatever this is : flat or pores…..

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

Cathode



$C + xLi^+ + xe^- \leftrightarrow Li_xC$

Anode

Ion diffusion : Interfaces
→ Particle size and NANO

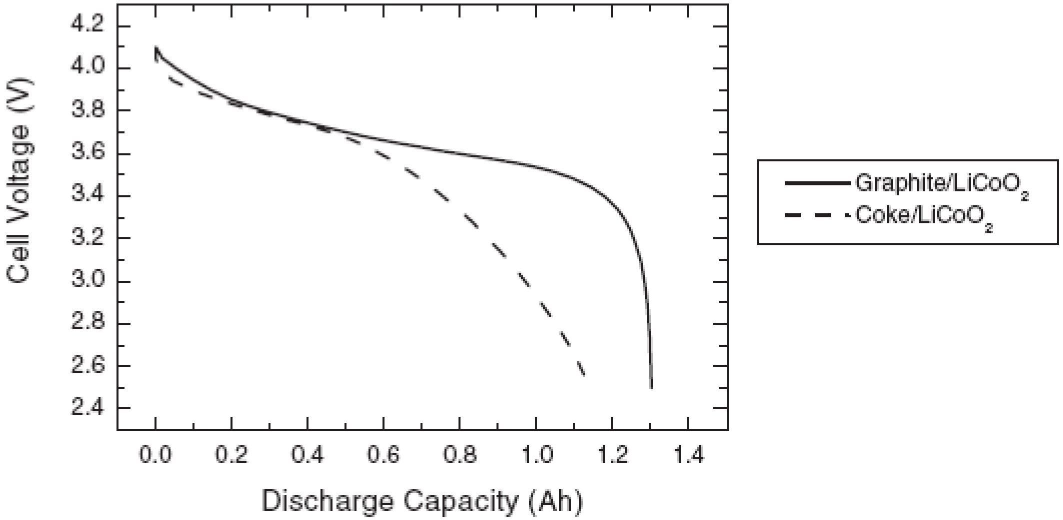


FIGURE 35.21 Effect of the carbon type on the discharge profile of Li-ion cells. (*Courtesy of the University of South Carolina.*)

Perfiles de Carga y Descarga

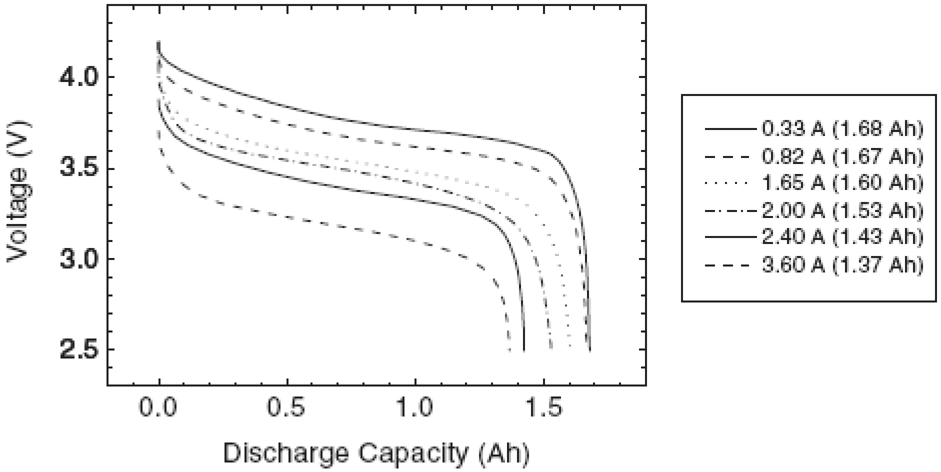


FIGURE 35.36 Discharge capability of 18650 type C/$LiCoO_2$ batteries at constant current at 21°C to 25°C. (*Courtesy of the University of South Carolina and NEC Moli Energy.*)

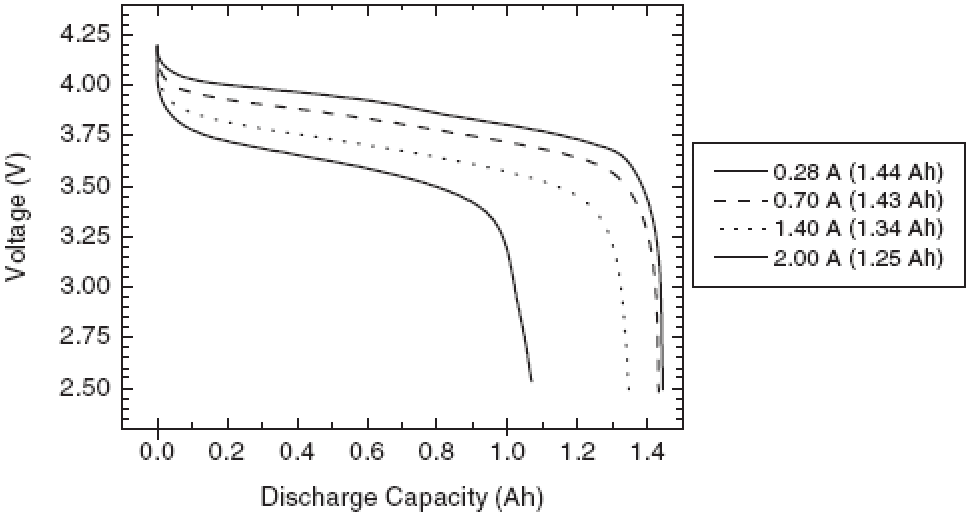


FIGURE 35.37 Rate capability of an 18650-type C/$LiMn_2O_4$ battery at constant current. The battery was charged in a CCCV (constant current-constant voltage) regime at 1.4 A to 4.2 V for 2.5 hours, then discharged at 21°C. (*Courtesy of NEC Moli Energy.*)

Velocidad de Descarga

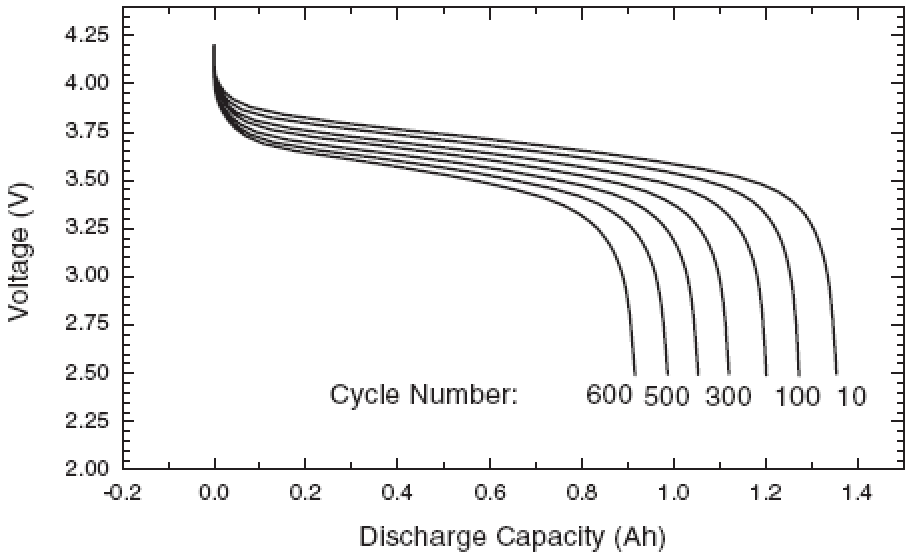


FIGURE 35.48 Discharge curves from an 18650-type C/$LiMn_2O_4$ battery at various cycle numbers illustrating the increase in resistance upon cycling. The battery was charged in a CCCV regime at 1.4 A to 4.2 V for 2.5 hours, and discharged at 1.35 A. (*Courtesy of NEC Moli Energy.*)

Evolucion de la capacidad

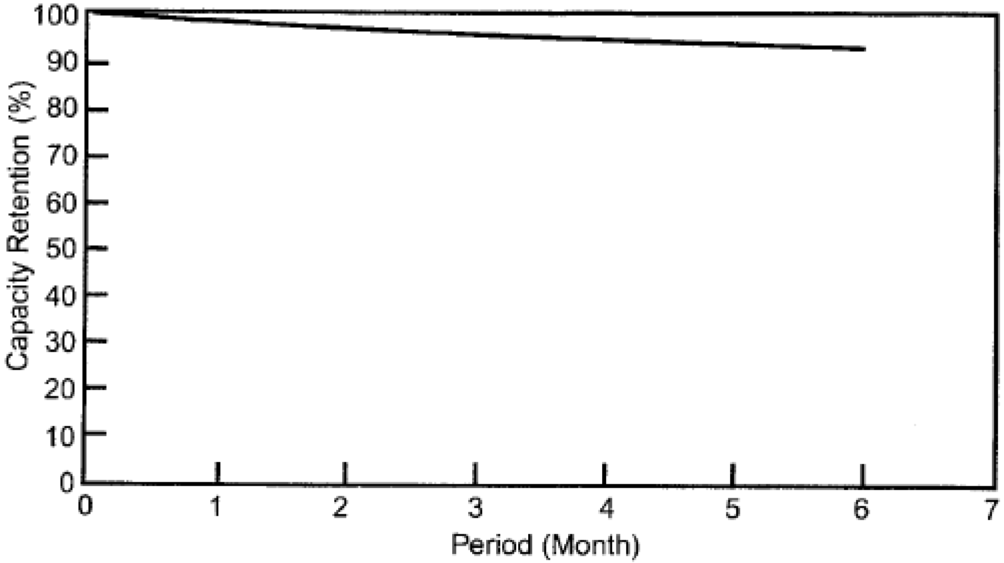


FIGURE 35.50 Self-discharge performance of a 17500-type cylindrical C/LiCoO$_2$ battery at 20°C when discharged after storage in the charged state for periods of up to six months. Charge conditions: Constant voltage/constant current, 4.2 V, 550 mA (max.), 2 hours, 20°C. Discharge conditions: Constant current 156 mA to 3.0 V at 20°C. (*Courtesy of Panasonic.*)

Fabricación de Baterías de Ión Litio

¿COMO ES UNA BATERIA DE ION LITIO POR DENTRO?

cilindrica

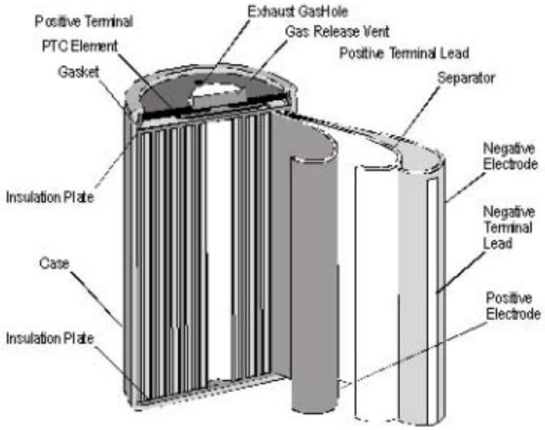
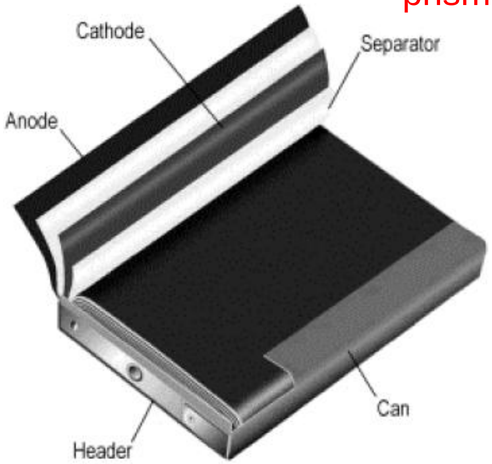


Figure 3-1: Cross-section of a classic NiCd cell.

prismatica



igure 3-3: Cross-section of a prismatic cell.

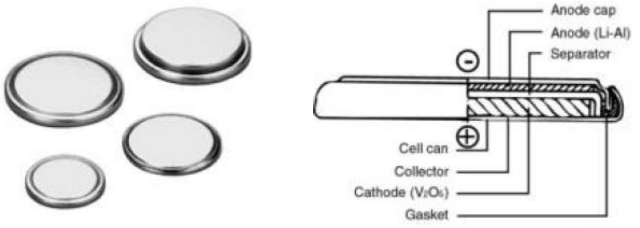
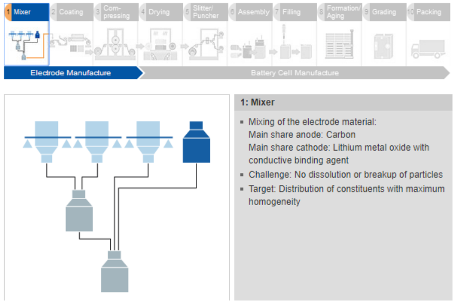


Figure 3-2: The button cell.

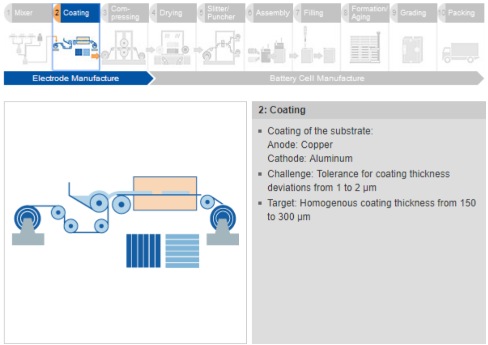
boton

Swiss roll



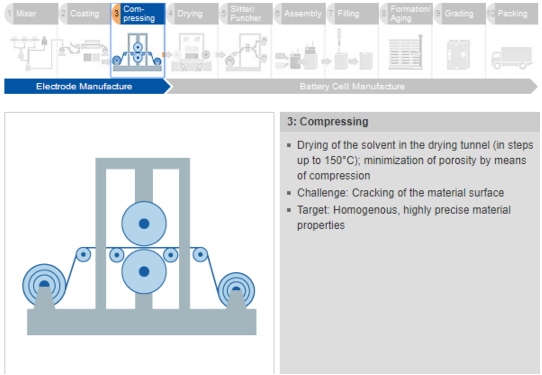
1: Mixer

- Mixing of the electrode material:
  Main share anode: Carbon
  Main share cathode: Lithium metal oxide with conductive binding agent
- Challenge: No dissolution or breakup of particles
- Target: Distribution of constituents with maximum homogeneity



2: Coating

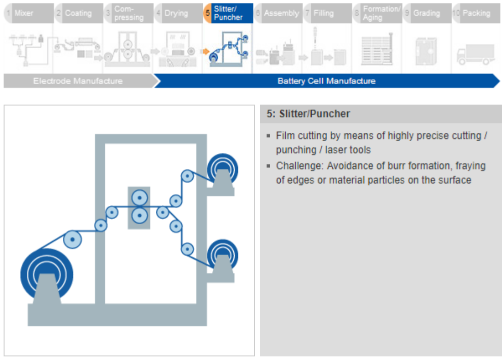
- Coating of the substrate:
  Anode: Copper
  Cathode: Aluminum
- Challenge: Tolerance for coating thickness deviations from 1 to 2 μm
- Target: Homogenous coating thickness from 150 to 300 μm



3: Compressing

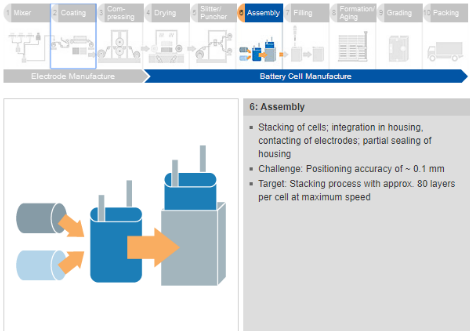
- Drying of the solvent in the drying tunnel (in steps up to 150°C); minimization of porosity by means of compression
- Challenge: Cracking of the material surface
- Target: Homogenous, highly precise material properties

Planta piloto de baterías de ion litio en Potosí, Bolivia.



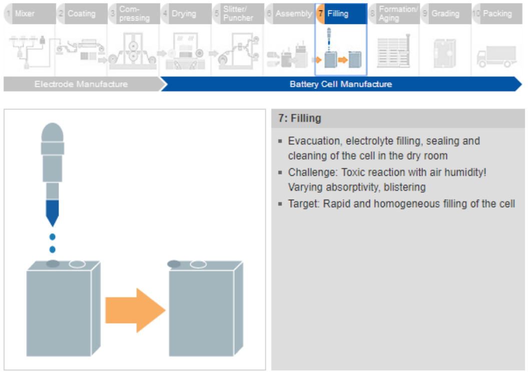
5: Slitter/Puncher

- Film cutting by means of highly precise cutting / punching / laser tools
- Challenge: Avoidance of burr formation, fraying of edges or material particles on the surface



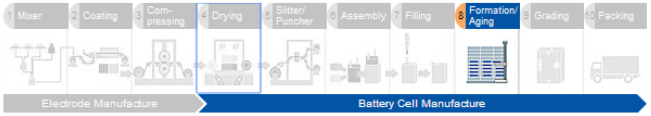
6: Assembly

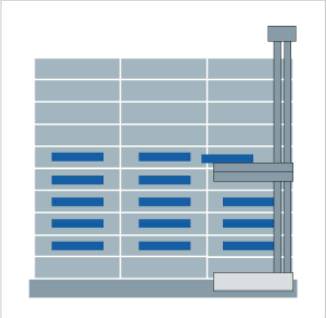
- Stacking of cells; integration in housing, contacting of electrodes; partial sealing of housing
- Challenge: Positioning accuracy of ~ 0.1 mm
- Target: Stacking process with approx. 80 layers per cell at maximum speed



7: Filling

- Evacuation, electrolyte filling, sealing and cleaning of the cell in the dry room
- Challenge: Toxic reaction with air humidity! Varying absorptivity, blistering
- Target: Rapid and homogeneous filling of the cell





8: Formation/ageing

- Activation by means of charging / discharging routines with gradually increasing voltage storage for 2 to 4 weeks
- Challenge: High time and cost expenditures, increased risk of fire
- Target: Assurance of operability; preparation for categorization