

ADJUNTO

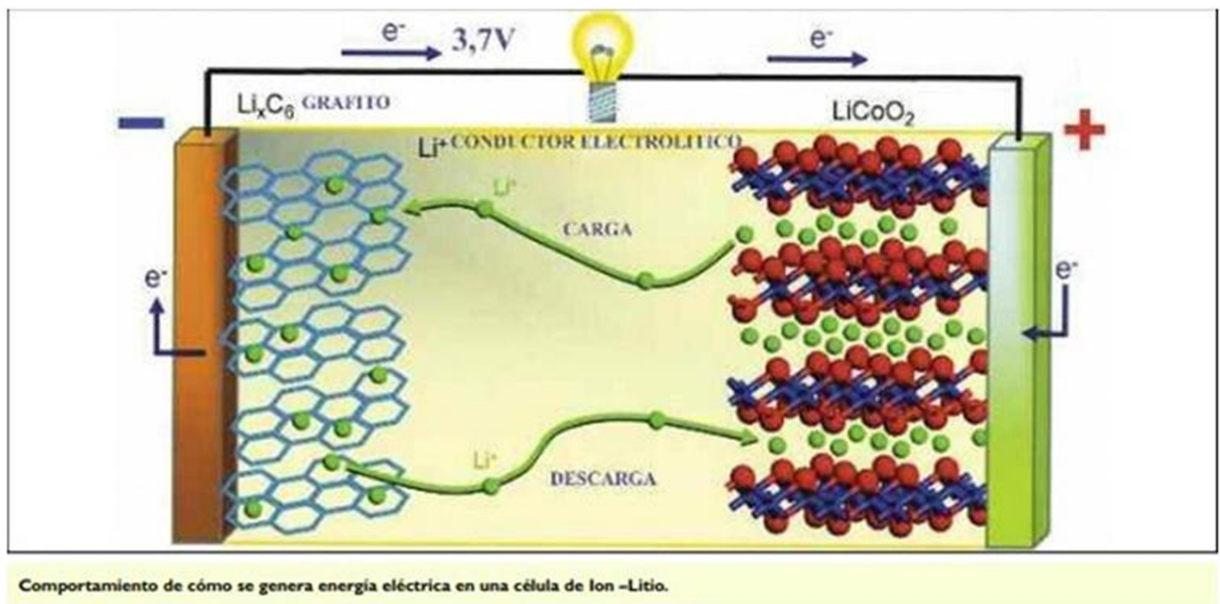


Figura 1. Proceso electroquímico en la batería de ion Litio. Fuente: <https://talleractual.com/tecnica/electronica-y-electricidad/7134-baterias-de-ion-litio-para-autos-electricos>

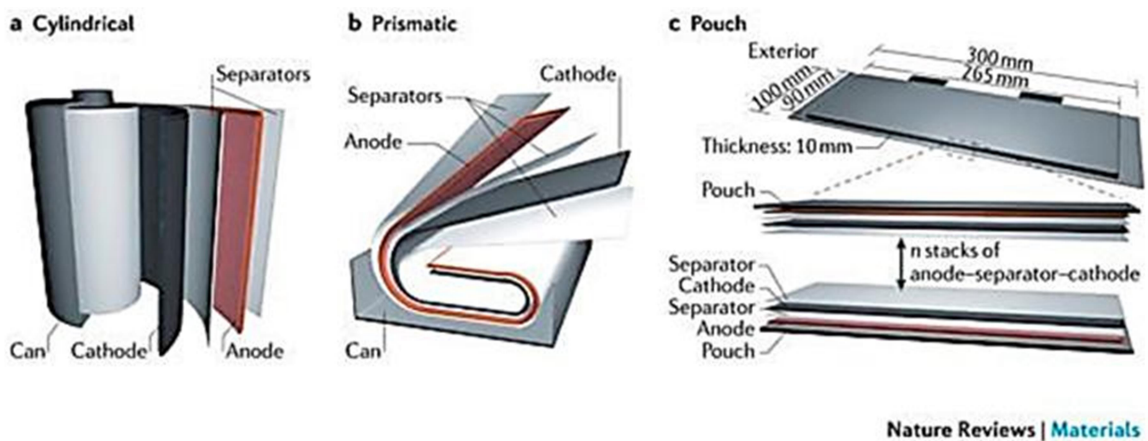


Figura 2. Geometrías más habituales de las baterías de ion-litio. Fuente: <https://blogs.cdecomunicacion.es/ignacio/2019/04/23/baterias-de-ion-litio-economia/>

Tabla 1. Disponibilidad global de materias primas para baterías de ión litio. Fuente: [4].

Element	Top mine producer	2017 mine production (1000 metric tons)	Reserves (1000 metric tons)	Top countries where reserves exist	Resources
Aluminum [15]	Australia, China, Guinea	300,000	30,000,000	Guinea, Australia, Vietnam	55 billion to 75 billion tons
Cobalt [16]	Congo, Russia Australia	110	7100	Congo, Australia, Cuba	25 million tons ^a
Copper [17]	Chile, Peru, China	19,700	790,000	Chile, Australia, Peru	2.1 billion tons
Iron [18]	Australia, Brazil, China	2,400,000	170,000,000	Australia, Russia, Brazil	> 800 billion tons
Lithium [19]	Australia, Chile, Argentina	43	16,000	Chile, Australia, China	> 53 million tons
Manganese [20]	South Africa, China, Australia	16,000	680,000	South Africa, Ukraine, Brazil	Abundant
Natural graphite ^b [21]	China, India, Brazil	1200	270,000	Turkey, Brazil, China	> 800 million tons
Nickel [22]	Indonesia, Philippines, Canada	2100	74,000	Australia, Brazil, Russia	> 130 million tons
Phosphorus [23]	China, United States, Morocco	263,000	70,000,000	Morocco, China, Algeria	> 300 billion tons
Silicon [24]	China, Russia, United States	7400	Abundant		Abundant
Tin [25]	China, Indonesia, Burma	290	4800	China, Indonesia, Brazil	Abundant
Titanium [26]	South Africa, Australia, China	7100	930,000	Australia, China, India	> 2 billion tons

^aThis number is for terrestrial resource of cobalt. More than 120 million tons of resources were identified on the floor of Atlantic, Indian, and Pacific Oceans, which would have technical difficulty for extraction

^bThree types of natural graphite (amorphous, flake, and lump or vein graphite) are included in this number

Tabla 2. Resumen de condiciones de lixiviación para la recuperación de metales en baterías de ión litio. Fuente: [1]

Waste cathode material	Concentration of acid and reductant (M)	Leaching Conditions	Efficiency (%)
LiCoO ₂	1.25 M citric acid +1% H ₂ O ₂	90 °C, 30 min, 20 g/L	Leaching(%): 90 Co & 100 Li
LiCoO ₂	1.25 M ascorbic acid	70 °C, 20 min, 25 g/L	Leaching(%): 94.8 Co & 98.5 Li
LiNi _{1/3} Co _{1/3} Mn _{1/3} O ₂	4 M aspartic acid + 2 M H ₂ O ₂	90 °C, 120 min, 125 g/L	Recovery(%): 85 Ni, 99 Co & 100 Mn
LiCoO ₂	4 M oxalic acid + 15% H ₂ O ₂	80 °C, 120 min, 50 g/L	Leaching(%): 68 Co & 98 Li
LiCoO ₂	1.5 M succinic acid + 4% H ₂ O ₂	70 °C, 40 min, 15 g/L	Leaching(%): 100 Co & 96 Li
LiMn ₂ O ₄	2 M HNO ₃	80 °C, 60 min	Recovery(%): 100 Li & 95 Mn
LiCoO ₂	1 M HNO ₃ + 1.7% H ₂ O ₂	75 °C, 30 min, 20 g/L	Leaching(%): > 95 Co & Li
Mixed cathode material	4 M HCl	80 °C, 60 min, 20 g/L	Leaching(%): 96.97 Li & 98.23Mn & 96.94 Co & 97.43 Ni
LiCoO ₂	4 M HCl	80 °C, 60 min, 100 g/L	Leaching(%): > 90 Co & Li
Waste NCM materials	4 M H ₂ SO ₄ + 2 times amount of H ₂ O ₂	90 °C, 120 min, 125 g/L	Leaching(%): 98 Ni & 99 Co & 84 Mn
LiNi _{1/3} Co _{1/3} Mn _{1/3} O ₂	4 M H ₂ SO ₄ + 10% H ₂ O ₂	85 °C, 120 min, 100 g/L	Recovery(%): 98 Co, 97 Mn & Ni
LiCoO ₂	4 M H ₂ SO ₄ + 10% H ₂ O ₂	85 °C, 120 min, 100 g/L	Leaching(%): 95 Co & 96 Li
LiCoO ₂	2 M H ₂ SO ₄ + 2% H ₂ O ₂	60 °C, 120 min, 33 g/L	Leaching(%): 96.3 Co & 87.5 Li

Tabla 3: Lista de ensayos extraída de Software R al aplicar DBB de tres factores en tres niveles con tres repeticiones del punto central.

	Temperatura (°C)	Tiempo (min)	Concentración ácido cítrico (mol L-1)
C0	150	55	1,25
C1	150	100	2
C2	150	10	0,5
C4	200	55	0,5
C5	100	55	0,5
C6	100	100	1,25
C7	100	10	1,25
C8	200	10	1,25
C9	150	55	1,25
C10	100	55	2
C11	150	100	0,5
C12	150	10	2
C13	200	55	2
C14	200	100	1,25
C15	150	55	1,25

Tabla 4: Resultados MP-AES del material catódico (por triplicado) y de LiFePO₄ puro (por duplicado junto al contenido teórico).

Muestra	% litio (m/m)	% hierro (m/m)	% fósforo (m/m)
Cátodo LFP (1)	3,2	-	-
Cátodo LFP (2)	2,9	26,8	46,5
Cátodo LFP (3)	2,2	29,3	45,8
LiFePO₄ (1)	3,4	27,8	38,3
LiFePO₄ (2)	3,6	25,3	34,5
LiFePO₄ (teórico)	4,4	34,5	19,5