# Accumulatori al litio e litio ione

# Tabella dei potenziali standard di semielementi (25°C) rispetto al SHE

| Reazioni | E° V |
|---|---|
| $Li^+ + e \rightarrow Li$ | -3.045 |
| $K^+ + \rightarrow K$ | -2.924 |
| $Ca^{2+} + 2e \rightarrow Ca$ | -2.76 |
| $Na^+ + e \rightarrow Na$ | -2.7109 |
| $Mg^{2+} + 2e \rightarrow Mg$ | -2.375 |
| $H_3O^+ + e \rightarrow H_2O + H$ | -2.10 |
| $Al^{3+} + 3e \rightarrow Al$ | -1.71 |
| $Ti^{2+} + 2e \rightarrow Ti$ | -1.63 |
| $ZnO_2^{2-} + 2H_2O + 2e \rightarrow Zn + 4OH^-$ | -1.22 |
| $Mn^{2+} + 2e \rightarrow Mn$ | -1.03 |
| $2H_2O + 2e \rightarrow H_2 + 2OH^-$ | -0.828 |
| Zn2+ + 2e $\rightarrow$ Zn | -0.763 |
| Cr3+ + 3e $\rightarrow$ Cr | -0.74 |
| $Te + 2H_3O^+ + 2e \rightarrow H_2Te + 2H_2O$ | -0.72 |
| $As + 3H_3O^+ + 3e \rightarrow AsH_3 + 3H_2O$ | -0.60 |
| $Cr^{2+} + 2e \rightarrow Cr$ | -0.557 |
| $H_3PO_2 + H_3O^+ + e \rightarrow P + 3H_2O$ | -0.51 |
| $Fe^{2+} + 2e \rightarrow Fe$ | -0.409 |
| $Cr^{3+} + e \rightarrow Cr^{2+}$ | -0.41 |
| $Cd^{2+} + 2e \rightarrow Cd$ | -0.4026 |
| $Se + 2H_3O^+ + 2e \rightarrow H_2Se + 2H_2O$ | -0.40 |
| $Tl^+ + e \rightarrow Tl$ | -0.3363 |
| $Co^{2+} + 2e \rightarrow Co$ | -0.277 |
| $Ni^{2+} + 2e \rightarrow Ni$ | -0.230 |
| $Sn^{2+} + 2e \rightarrow Sn$ | -0.1364 |
| $Pb^{2+} + 2e \rightarrow Pb$ | -0.1263 |
| $2H_3O^+ + 2e \rightarrow H_2 + 2H_2O$ | 0.0000 |

| Reazioni | E° V |
|---|---|
| $S + 2H_3O^+ + 2e \rightarrow H_2S + 2H_2O$ | 0.14 |
| $Sn^{4+} + 2e \rightarrow Sn^{2+}$ (HCl 1F) | 0.15 |
| $Cu^{2+} + e \rightarrow Cu^+$ | 0.158 |
| $Hg_2Cl_2 + 2e \rightarrow 2Hg + 2Cl^-$ | 0.2682 |
| $Cu^{2+} + 2e \rightarrow Cu$ | 0.337 |
| $O_2 + 2H_2O + 4e \rightarrow 4OH^-$ | 0.401 |
| $Cu^+ + e \rightarrow Cu$ | 0.521 |
| $I_2 + 2e \rightarrow 2I^-$ | 0.536 |
| $O_2 + 2H_3O^+ + 2e \rightarrow H_2O_2 + 2H_2O$ | 0.682 |
| $Fe^{3+} + e \rightarrow Fe^{2+}$ | 0.771 |
| $Hg_2^{2+} + 2e \rightarrow 2Hg$ | 0.7961 |
| $Ag^+ + e \rightarrow Ag$ | 0.7996 |
| $2NO_3^- + 4H_3O^+ + 2e \rightarrow N_2O_4 + 6H_2O$ | 0.80 |
| $NO_3^- + 3H_3O^+ + 2e \rightarrow HNO_2 + 4H_2O$ | 0.94 |
| $NO_3^- + 4H_3O^+ + 3e \rightarrow NO + 6H_2O$ | 0.96 |
| $Br_2 + 2e \rightarrow 2Br^-$ | 1.087 |
| $Pt^{2+} + 2e \rightarrow Pt$ | 1.2 |
| $MnO_2 + 4H_3O^+ + 2e \rightarrow Mn^{2+} + 6H_2O$ | 1.21 |
| $O_2 + 4H_3O^+ + 4e \rightarrow 6H_2O$ | 1.229 |
| $Cr_2O_7^{2-} + 14H_3O^+ + 6e \rightarrow 2Cr^{3+} + 21H_2O$ | 1.33 |
| $Cl_2 + 2e \rightarrow 2Cl^-$ | 1.358 |
| $ClO_3^- + 6H_3O^+ + 6e \rightarrow 6Cl^- + 9H_2O$ | 1.45 |
| $PbO_2 + 4H_3O^+ + 2e \rightarrow Pb^{2+} + 6H_2O$ | 1.455 |
| $MnO_4^- + 8H_3O^+ + 5e \rightarrow Mn^{2+} + 12H_2O$ | 1.50 |
| $HClO + H_3O^+ + e \rightarrow 1/2Cl_2 + 2H_2O$ | 1.63 |
| $H_2O_2 + 2H_3O^+ + 2e \rightarrow 4H_2O$ | 1.776 |
| $F_2 + 2e \rightarrow 2F^-$ | 2.866 |

# Gli accumulatori elettrochimici

**Un accumulatore è un elemento voltaico analogo ad una pila**

SCARICA

***Energia Chimica*** ⇄ ***Energia Elettrica***

CARICA

**La ricarica dell'accumulatore si ottiene mediante il suo collegamento ad un generatore di corrente continua.**

# Caratteristiche di alcuni materiali

Characteristics of Electrode Materials

| Material | Atomic or molecular weight, g | Standard reduction potential at 25°C, V | Valence change | Melting point, °C | Density, $g/cm^3$ | Electrochemical equivalents | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Ah/g | g/Ah | $Ah/cm^3$‡ |
| | | | | Anode materials | | | | |
| $H_2$ | 2.01 | 0<br>−0.83† | 2 | — | — | 26.59 | 0.037 | |
| Li | 6.94 | −3.01 | 1 | 180 | 0.54 | 3.86 | 0.259 | 2.06 |
| Na | 23.0 | −2.71 | 1 | 98 | 0.97 | 1.16 | 0.858 | 1.14 |
| Mg | 24.3 | −2.38<br>−2.69† | 2 | 650 | 1.74 | 2.20 | 0.454 | 3.8 |
| Al | 26.9 | −1.66 | 3 | 659 | 2.69 | 2.98 | 0.335 | 8.1 |
| Ca | 40.1 | −2.84<br>−2.35† | 2 | 851 | 1.54 | 1.34 | 0.748 | 2.06 |
| Fe | 55.8 | −0.44<br>−0.88† | 2 | 1528 | 7.85 | 0.96 | 1.04 | 7.5 |
| Zn | 65.4 | −0.76<br>−1.25† | 2 | 419 | 7.14 | 0.82 | 1.22 | 5.8 |
| Cd | 112.4 | −0.40<br>−0.81† | 2 | 321 | 8.65 | 0.48 | 2.10 | 4.1 |
| Pb | 207.2 | −0.13 | 2 | 327 | 11.34 | 0.26 | 3.87 | 2.9 |
| $(Li)C_6$[1] | 72.06 | ∼−2.8 | 1 | — | 2.25 | 0.37 | 2.68 | 0.84 |
| MH[2] | 116.2 | −0.83† | 2 | — | — | 0.45 | 2.21 | — |
| $CH_3OH$ | 32.04 | — | 6 | — | — | 5.02 | 0.20 | — |

Characteristics of Electrode Materials

| Material | Atomic or molecular weight, g | Standard reduction potential at 25°C, V | Valence change | Melting point, °C | Density, g/cm$^3$ | Electrochemical equivalents Ah/g | g/Ah | Ah/cm$^3$‡ |
|---|---|---|---|---|---|---|---|---|
| | | | Cathode materials | | | | | |
| $O_2$ | 32.0 | 1.23<br>0.40† | 4 | — | — | 3.35 | 0.30 | |
| $Cl_2$ | 71.0 | 1.36 | 2 | — | — | 0.756 | 1.32 | |
| $SO_2$ | 64.0 | — | 1 | — | — | 0.419 | 2.38 | |
| $MnO_2$ | 86.9 | 1.28‡ | 1 | — | 5.0 | 0.308 | 3.24 | 1.54 |
| NiOOH | 91.7 | 0.49† | 1 | — | 7.4 | 0.292 | 3.42 | 2.16 |
| CuCl | 99.0 | 0.14 | 1 | — | 3.5 | 0.270 | 3.69 | 0.95 |
| $FeS_2$ | 119.9 | — | 4 | — | — | 0.89 | 1.12 | 4.35 |
| AgO | 123.8 | 0.57† | 2 | — | 7.4 | 0.432 | 2.31 | 3.20 |
| $Br_2$ | 159.8 | 1.07 | 2 | — | — | 0.335 | 2.98 | |
| HgO | 216.6 | 0.10† | 2 | — | 11.1 | 0.247 | 4.05 | 2.74 |
| $Ag_2O$ | 231.7 | 0.35† | 2 | — | 7.1 | 0.231 | 4.33 | 1.64 |
| $PbO_2$ | 239.2 | 1.69 | 2 | — | 9.4 | 0.224 | 4.45 | 2.11 |
| $Li_xCoO_2$(3) | 98 | ~2.7 | 0.5 | — | — | 0.137 | 7.29 | — |
| $I_2$ | 253.8 | 0.54 | 2 | — | 4.94 | 0.211 | 4.73 | 1.04 |

† Basic electrolyte: all others, aqueous acid electrolyte.
‡ Based on density values shown.
(1) Calculations based only on weight of carbon.
(2) Based on 1.7% $H_2$ storage by weight.
(3) Based on x = 0.5; higher valves may be obtained in practice.

$LiNiO_2$ : 0.137 Ah/g
$LiMn_2O_4$ : 0.146 Ah/g
$LiFePO_4$ : 0.170 Ah/g

# Pile al litio

- Si dicono ***pile primarie*** tutti quei sistemi che ammettono una sola scarica e quindi non possono essere ricaricate

- Si dicono invece ***pile secondarie*** tutte quelle pile che dopo la scarica ammettono una ricarica che portano la pila nelle condizioni iniziali pronta per affrontare una nuova scarica. Sono quindi sistemi elettrochimici che possono affrontare cicli di scarica e carica. Le pile secondarie vengono dette anche accumulatori

**TABLE** Voltage, Capacity and Specific Energy of Major Battery Systems—Theoretical and Practical Values

| Battery type | Anode | Cathode | Reaction mechanism | Theoretical values† V | g/Ah | Ah/kg | Specific energy Wh/kg | Practical battery‡ Nominal voltage V | Specific energy Wh/kg | Energy density Wh/L |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Secondary batteries | | | | | | | |
| Lead-acid | Pb | $PbO_2$ | $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$ | 2.1 | 8.32 | 120 | 252 | 2.0 | 35 | 70[10] |
| Edison | Fe | Ni oxide | $Fe + 2NiOOH + 2H_2O \rightarrow 2Ni(OH)_2 + Fe(OH)_2$ | 1.4 | 4.46 | 224 | 314 | 1.2 | 30 | 55[10] |
| Nickel-cadmium | Cd | Ni oxide | $Cd + 2NiOOH + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2$ | 1.35 | 5.52 | 181 | 244 | 1.2 | 35 | 100[5] |
| Nickel-zinc | Zn | Ni oxide | $Zn + 2NiOOH + 2H_2O \rightarrow 2Ni(OH)_2 + Zn(OH)_2$ | 1.73 | 4.64 | 215 | 372 | 1.6 | 60 | 120 |
| Nickel-hydrogen | $H_2$ | Ni oxide | $H_2 + 2NiOOH \rightarrow 2Ni(OH)_2$ | 1.5 | 3.46 | 289 | 434 | 1.2 | 55 | 60 |
| Nickel-metal hydride | MH[1] | Ni oxide | $MH + NiOOH \rightarrow M + Ni(OH)_2$ | 1.35 | 5.63 | 178 | 240 | 1.2 | 75 | 240[5] |
| Silver-zinc | Zn | AgO | $Zn + AgO + H_2O \rightarrow Zn(OH)_2 + Ag$ | 1.85 | 3.53 | 283 | 524 | 1.5 | 105 | 180[10] |
| Silver-cadmium | Cd | AgO | $Cd + AgO + H_2O \rightarrow Cd(OH)_2 + Ag$ | 1.4 | 4.41 | 227 | 318 | 1.1 | 70 | 120[10] |
| Zinc/chlorine | Zn | $Cl_2$ | $Zn + Cl_2 \rightarrow ZnCl_2$ | 2.12 | 2.54 | 394 | 835 | — | — | — |
| Zinc/bromine | Zn | $Br_2$ | $Zn + Br_2 \rightarrow ZnBr_2$ | 1.85 | 4.17 | 309 | 572 | 1.6 | 70 | 60 |
| Lithium-ion | $Li_xC_6$ | $Li_{(i-x)}CoO_2$ | $Li_xC_6 + Li_{(i-x)}CoO_2 \rightarrow LiCoO_2 + C_6$ | 4.1 | 9.98 | 100 | 410 | 4.1 | 150 | 400[5] |
| Lithium/manganese dioxide | Li | $MnO_2$ | $Li + Mn^{IV}O_2 \rightarrow Mn^{IV}O_2(Li^+)$ | 3.5 | 3.50 | 286 | 1001 | 3.0 | 120 | 265 |
| Lithium/iron disulfide[2] | Li(Al) | $FeS_2$ | $2Li(Al) + FeS_2 \rightarrow Li_2FeS_2 + 2Al$ | 1.73 | 3.50 | 285 | 493 | 1.7 | 180[11] | 350[11] |
| Lithium/iron monosulfide[2] | Li(Al) | FeS | $2Li(Al) + FeS \rightarrow Li_2S + Fe + 2Al$ | 1.33 | 2.90 | 345 | 459 | 1.3 | 130[11] | 220[11] |
| Sodium/sulfur[2] | Na | S | $2Na + 3S \rightarrow Na_2S_3$ | 2.1 | 2.65 | 377 | 792 | 2.0 | 170[11] | 345[11] |
| Sodium/nickel chloride[2] | Na | $NiCl_2$ | $2Na + NiCl_2 \rightarrow 2NaCl + Ni$ | 2.58 | 3.28 | 305 | 787 | 2.6 | 115[11] | 190[11] |

†Based on active anode and cathode materials only, including $O_2$ but not air (electrolyte not included).

*These values are for single cell batteries based on identified design and at discharge rates optimized for energy density, using midpoint voltage. More specific values are given in chapters on each battery system.

(1) MH = metal hydride, data based on 1.7% hydrogen storage (by weight).
(2) High temperature batteries.
(3) Solid electrolyte battery ($Li/I_2$ (P2VP)).
(4) Cylindrical bobbin-type batteries.
(5) Cylindrical spiral-wound batteries.
(6) Button type batteries.
(7) Water-activated.
(8) Automatically activated 2- to 10-min rate.
(9) With lithium anodes.
(10) Prismatic batteries.
(11) Value based on cell performance, see appropriate chapter for details.

**TABLE** Voltage, Capacity and Specific Energy of Major Battery Systems—Theoretical and Practical Values

| Battery type | Anode | Cathode | Reaction mechanism | Theoretical values† V | Theoretical values† g/Ah | Theoretical values† Ah/kg | Theoretical values† Specific energy Wh/kg | Practical battery‡ Nominal voltage V | Practical battery‡ Specific energy Wh/kg | Practical battery‡ Energy density Wh/L |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fuel cells | | | | | | | |
| $H_2/O_2$ | $H_2$ | $O_2$ | $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ | 1.23 | 0.336 | 2975 | 3660 | | | |
| $H_2$/air | $H_2$ | Ambient air | $H_2 + (\frac{1}{2}O_2) \rightarrow H_2O$ | 1.23 | 0.037 | 26587 | 32702 | | | |
| Methanol/$O_2$ | $CH_3OH$ | $O_2$ | $CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O$ | 1.24 | 0.50 | 2000 | 2480 | — | — | — |
| Methanol/air | $CH_3OH$ | Ambient air | $CH_3OH + (\frac{3}{2}O_2) \rightarrow CO_2 + 2H_2O$ | 1.24 | 0.20 | 5020 | 6225 | — | — | — |

# Tipi di accumulatori elettrochimici commerciali

| Caratteristiche | Piombo-acido | Ni-Cd | Ni-MH | Litio-ione |
|---|---|---|---|---|
| Potenziale di scarica | 2.1 V | 1.2 V | 1.2 V | 3.2-4V |
| Energia specifica | 40 Wh/Kg | 50 Wh/Kg | 60 Wh/Kg | >100Wh/Kg |
| Cicli di vita | 200-300 | 1000-1500 | 300-500 | 1000 |
| Costo per ciclo | 0.25 $ | 0.06 $ | 0.1 $ | 0.08-0.05 $ |
| Autoscarica | 21 % | 15 % | 20 % | 12 % |
| Densità di potenza | 210 W/l | 1000 W/l | 800 W/l | 500 W/l |
| Intervallo di temperatura | -15, +40 °C | -40, +45°C | -40, +45°C | -20, +50°C |

Le batterie Litio-ione hanno prestazioni superiori

- Elevata energia specifica
- Alto numero di cicli
- Basso costo per ciclo

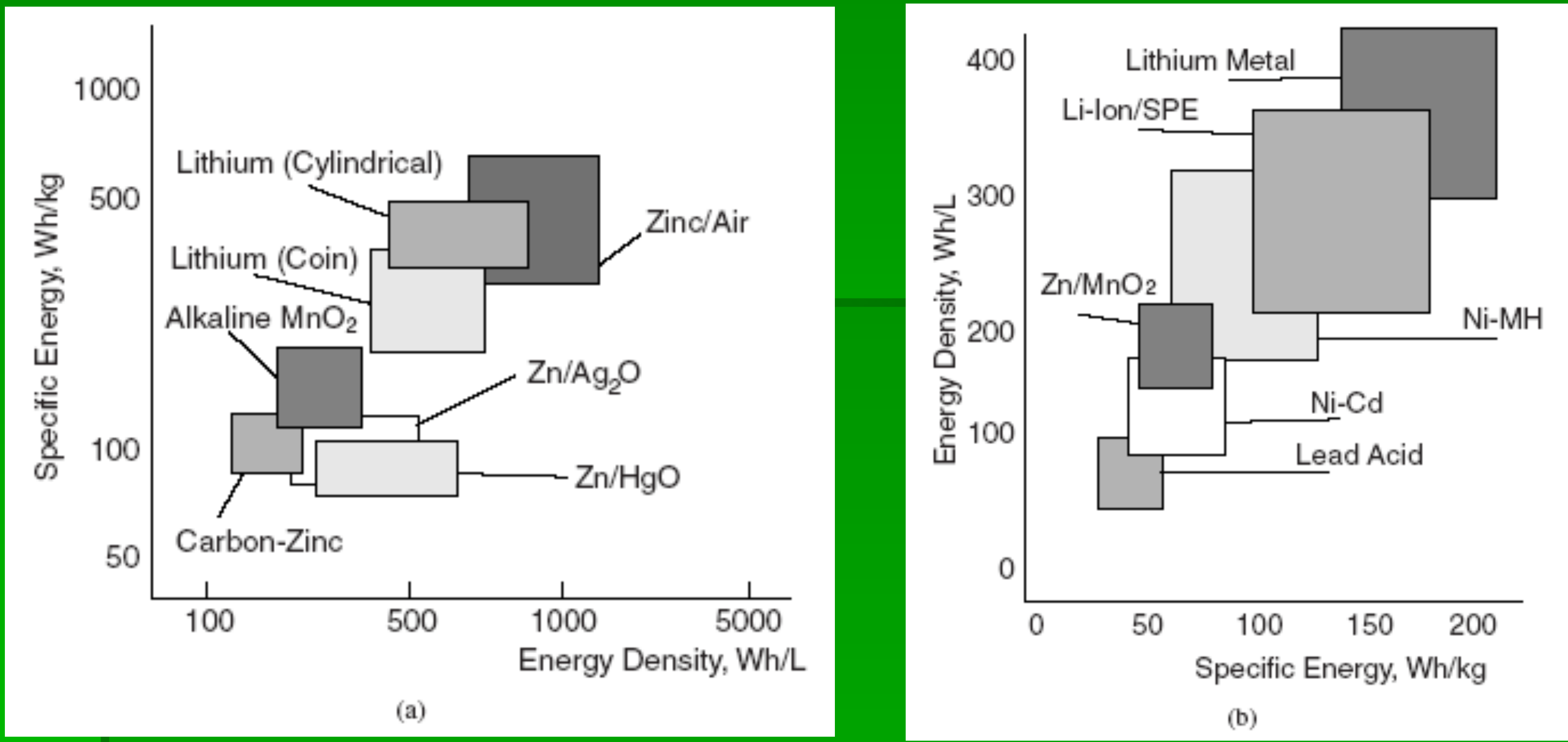



**FIGURE** Comparison of the energy storage capability of various battery systems (*a*) Primary batteries; (*b*) Rechargeable batteries.

# Solvente

Assolutamente non acquoso

- Caratteristiche

- Aprotico
- Termodinamicamente e cineticamente stabile rispetto al litio
- Bassa viscosità
- Alta costante dielettrica
- Alto potere solvatante
- Finestra elettrochimica tra 0 e 5 Vol
- Non tossico
- Facilmente disponibile
- Basso costo
- Buona conducibilità
- Termicamente stabile (sopra i 70 °C)
- Compatibilità con i componenti della cella

# Proprietà di alcuni solventi organici

**TABLE 11.5** Properties of Organic Electrolyte Solvents for Lithium Primary Batteries

| Solvent | Structure | Boiling point (at $10^5$ Pa), °C | Melting point, °C | Flash point, °C | Density (at 25°C), g/cm³ | Specific conductivity, with 1 M $LiClO_4$, $\Omega^{-1}\,cm^{-1}$ |
|---|---|---|---|---|---|---|
| Acetonitrile (AN) | $H_3C-C\equiv N$ | 81 | −45 | 5 | 0.78 | $3.6 \times 10^{-2}$ |
| γ-Butyrolactone (BL) | $H_2C-CH_2$ / $O$ and $CH_2$ / $C{=}O$ (five-membered ring) | 204 | −44 | 99 | 1.1 | $1.1 \times 10^{-2}$ |
| Dimethylsulfoxide (DMSO) | $H_3C-S(=O)-CH_3$ | 189 | 18.5 | 95 | 1.1 | $1.4 \times 10^{-2}$ |
| Dimethylsulfite (DMSI) | $O{=}S(OCH_3)_2$ | 126 | −141 | | 1.2 | |
| 1,2-Dimethoxyethane (DME) | $H_3C-O-CH_2-CH_2-O-CH_3$ | 83 | −60 | 1 | 0.87 | |
| Dioxolane (1,3-D) | $H_2C-O$ / $H_2C-O$ bridged by $CH_2$ (ring) | 75 | −26 | 2 | 1.07 | |
| Methyl formate (MF) | $H-C(=O)-O-CH_3$ | 32 | −100 | −19 | 0.98 | $3.2 \times 10^{-2}$ |
| Nitromethane (NM) | $H_3C-NO_2$ | 101 | −29 | 35 | 1.13 | $1 \times 10^{-2}$ |
| Propylene carbonate (PC) | $H_3C-CH-CH_2$ / $O$ and $O$ / $C{=}O$ (ring) | 242 | −49 | 135 | 1.2 | $7.3 \times 10^{-3}$ |
| Tetrahydrofuran (THF) | $H_2C-CH_2-CH_2-CH_2$ closed through $O$ (ring) | 65 | −103 | −15 | 0.89 | |

**Principali solventi utilizzati**

γ-BL: γ-Butirrolattone

THF: Tetraidrofurano

1,2 DME: 1,2 Dimetossietano

PC: Propilen Carbonato

DMC: Dimetil Carbonato

DEC: Dietil Carbonato

DEE: Dietil Etere

DIOX: Diossolano

**Principali elettroliti Utilizzati**

$LiPF_6$ Esafluoro fosfato di litio

$LiBF_4$ Tetrafluro borato di litio

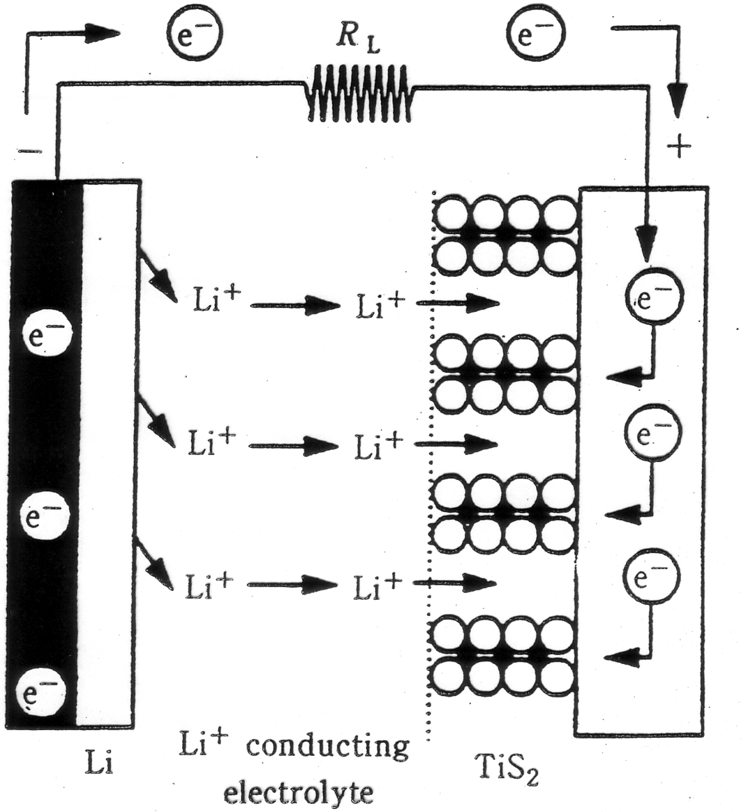
$LiClO_4$ Perclorato di litio

$LiAsF_6$ Esafluro arseniato di litio

**Alcune soluzioni utilizzate nelle celle litio-ione**

| | |
|---|---|
| PC/DEC 1 M $LiPF_6$ | Sony |
| EC/DMC 1 M $LiPF_6$ | Sanyo |
| PC/DME 1 M $LiPF_6$ | Rayovac |
| PC/DME 1 M $LiAsF_6$ | Saft |
| EC/DMC 1 M $LiPF_6$ | Bellcore |

# Reazioni di intercalazione e reversibilità del processo




Schematic of a $TiS_2/Li^+$ electrolyte/Li battery. Current flows represent discharge.

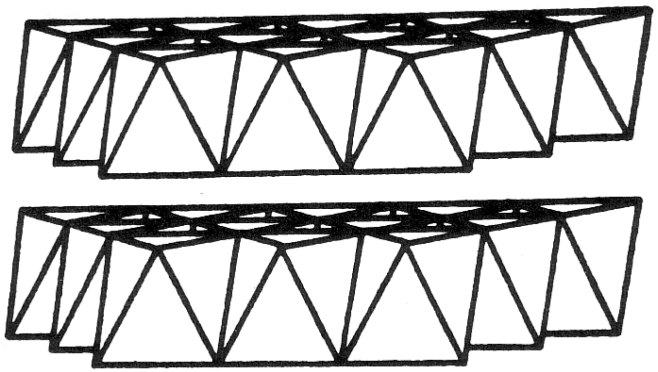
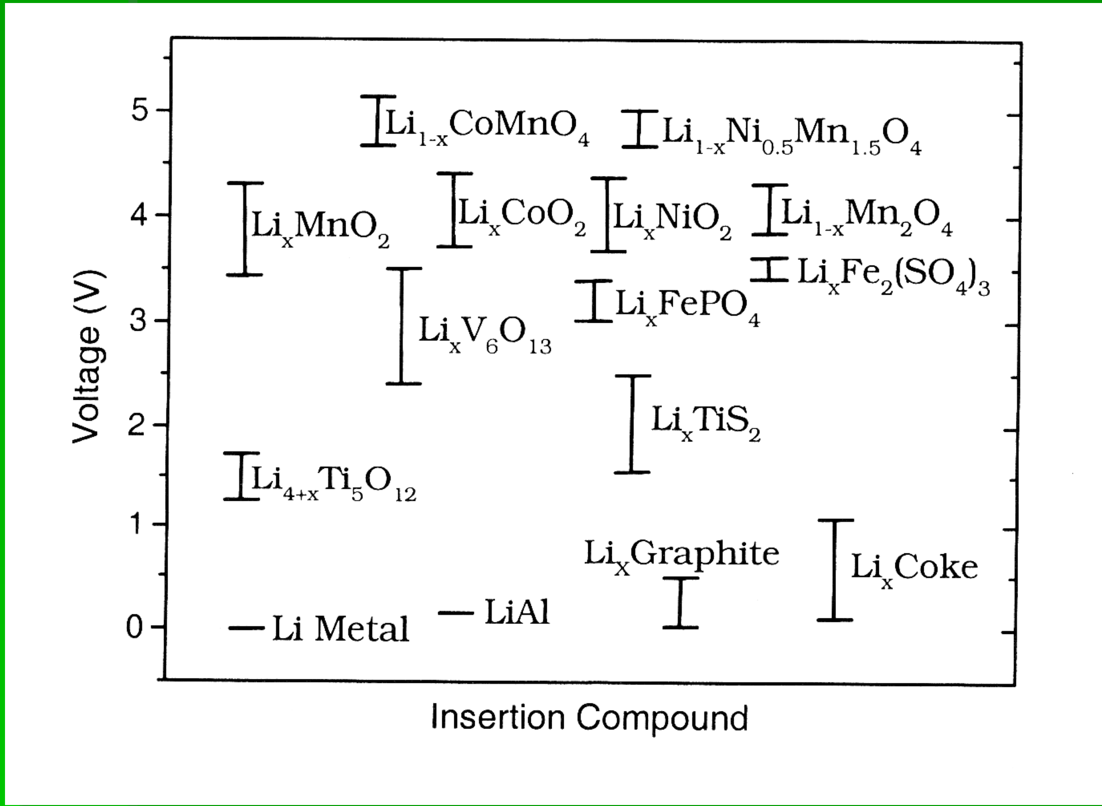


*Fig. 2. The lamellar $TiS_2$ structure formed from $TiS_6$ octahedra*

# Pile secondarie con anodo di litio metallico

- L'utilizzo di soluzioni elettrolitiche liquide ha creato seri problemi di sicurezza
- Oggi sono allo studio accumulatori con elettrolita polimerico in cui viene utilizato Li metallico

# Molti ossidi di metalli di transizione danno la reazione reversibile di intercalazione con il litio




Potenziali di intercalazione in alcuni materiali utilizzati nelle celle al litio

$LiNiO_2$, $LiCoO_2$, e $LiMn_2O_4$ presentano potenziali di intercalazione sopra ai 4 Volt

Il potenziale di intercalazione della grafite è il più vicino a quello del litio metallico

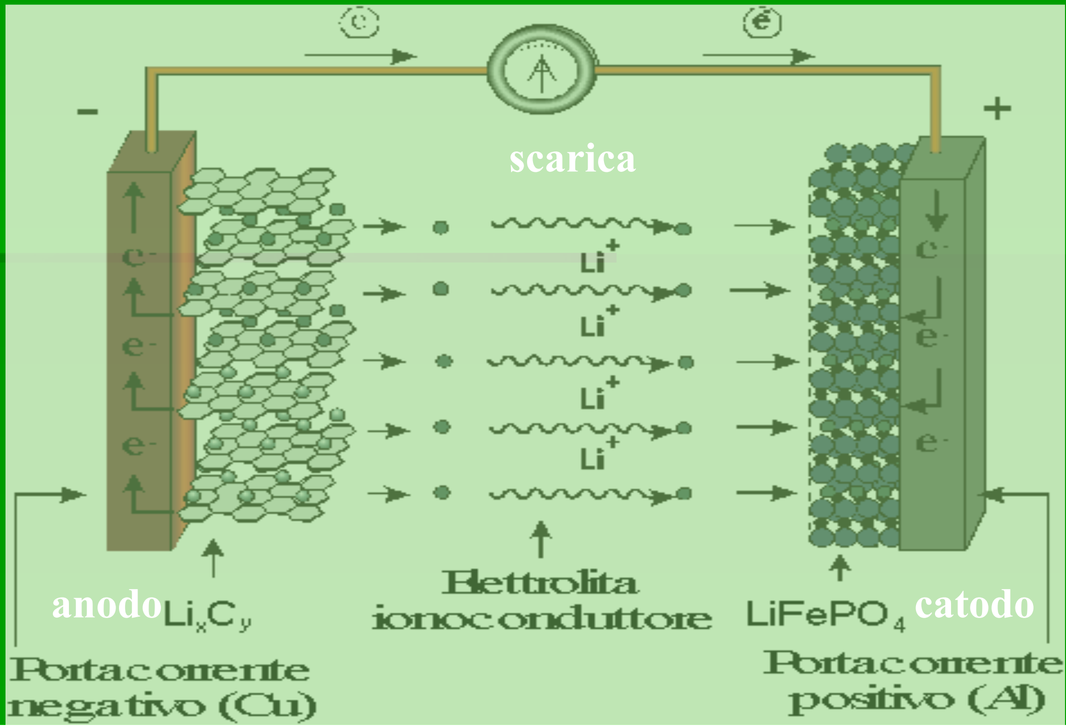
# Funzionamento delle batterie Litio-ione

Si basa sul processo di ***INTERCALAZIONE***

Gli ioni litio $Li^+$ vengono ospitati all'interno di una matrice solida (stratiforme o canaliforme) senza modificazione della struttura.

Anodo (-) — SCARICA → — Catodo (+)

GRAFITE — ← CARICA — $LiCoO_2$, $LiNiO_2$, $LiMn_2O_4$, $LiFePO_4$



# Strutture dei catodi

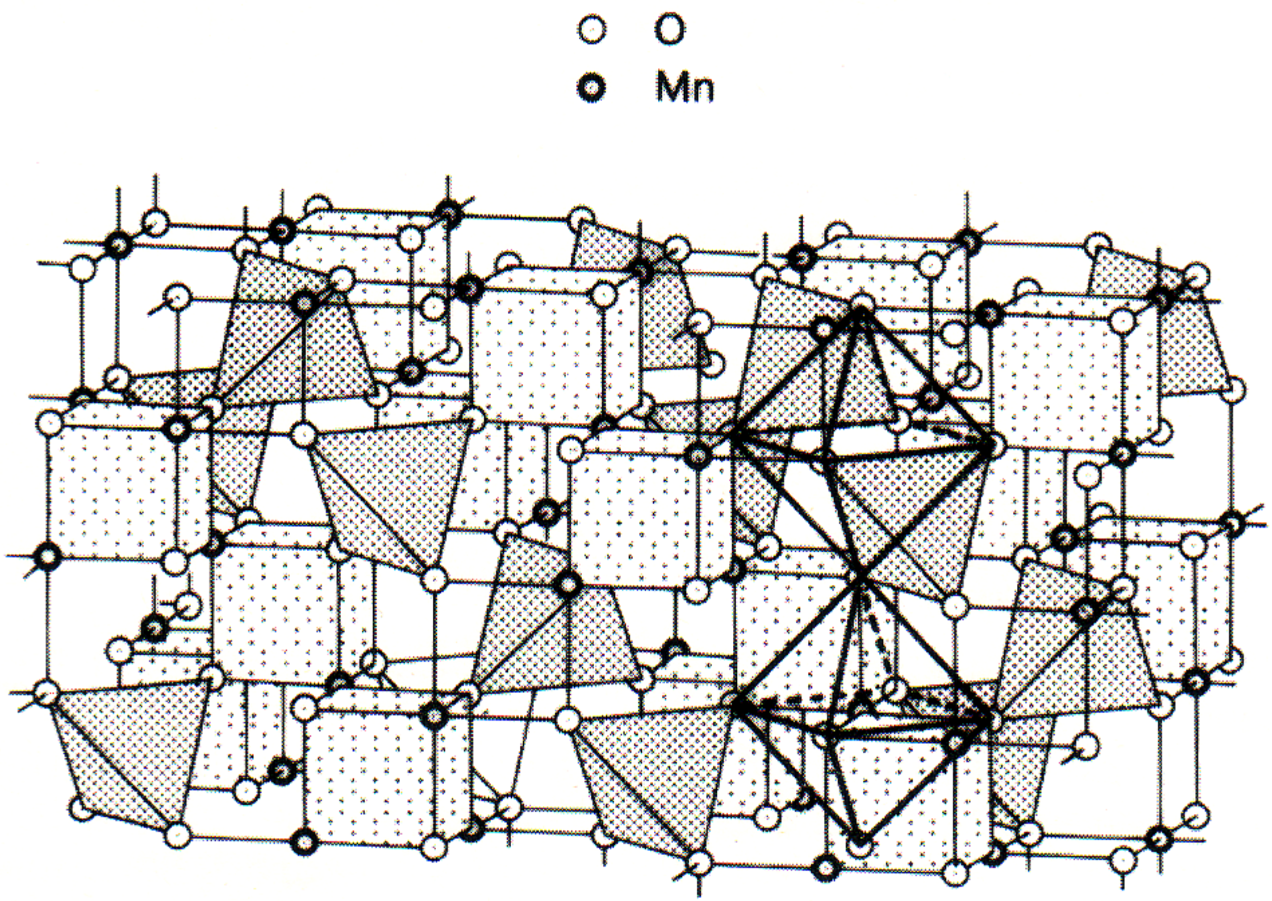
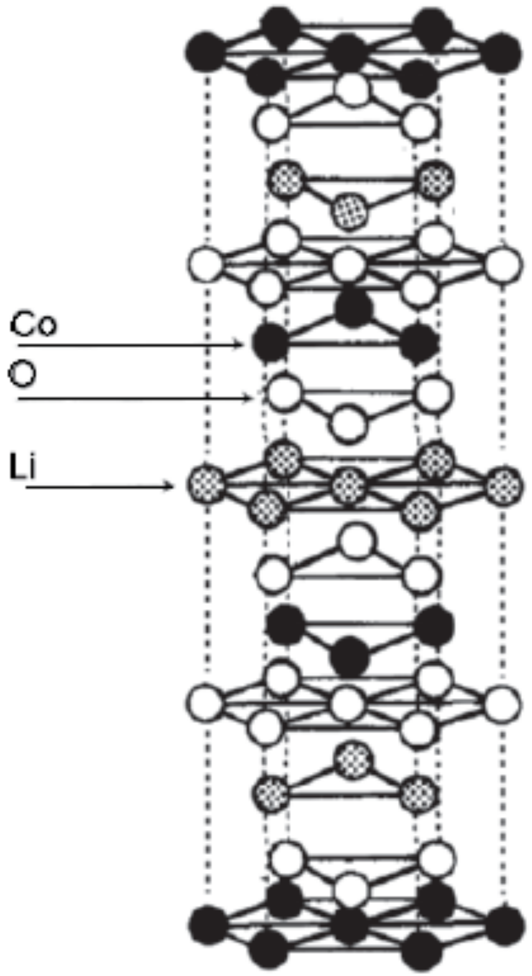



Fig. 1. The spinel structure. Two unit cells are shown. A 16d octahedron representing the coordination around Mn (lower) and an empty 16c octahedron (upper) are outlined. Adapted from Ref. 11.

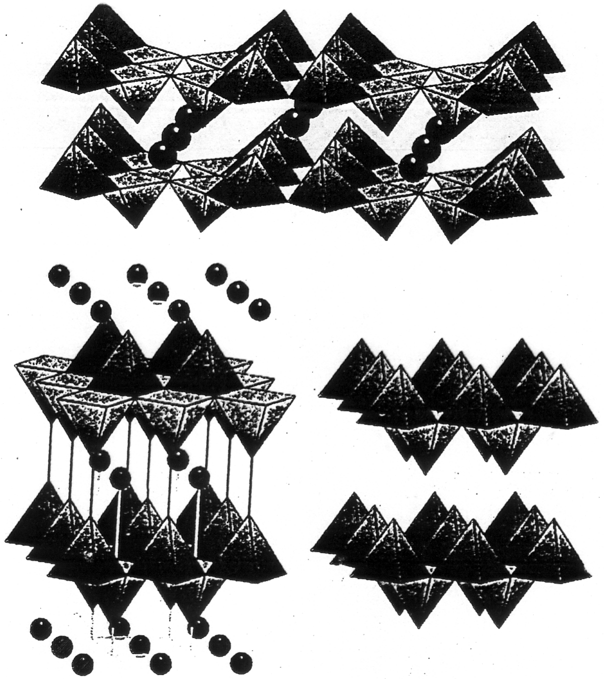
# Strutture dei catodi



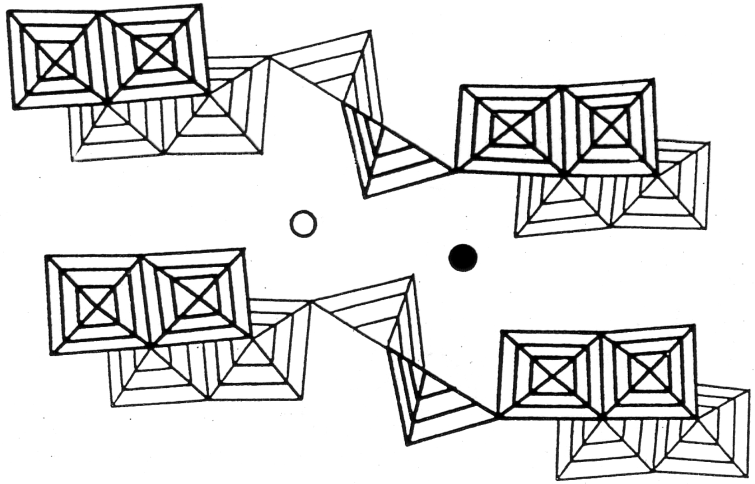

LiCoO2

**FIGURE** The idealized layered structure of $LiCoO_2$, Li is speckled, O white and Co black.

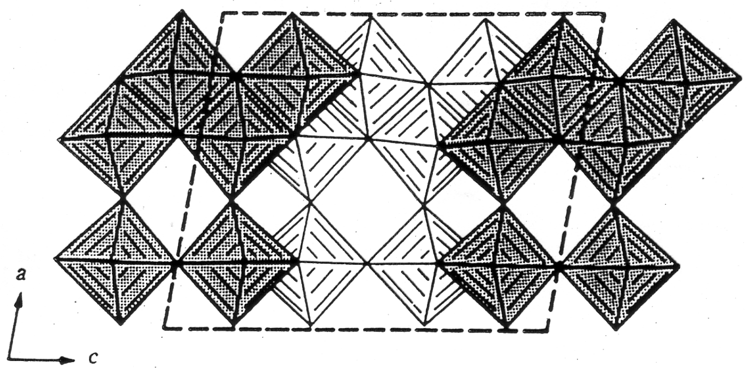
# Strutture dei catodi



Side view of sheets showing arrangements of $VO_5$ square pyramids in (top) $V_2O_5$ and (bottom) hydrated and anhydrous $VO_2$.

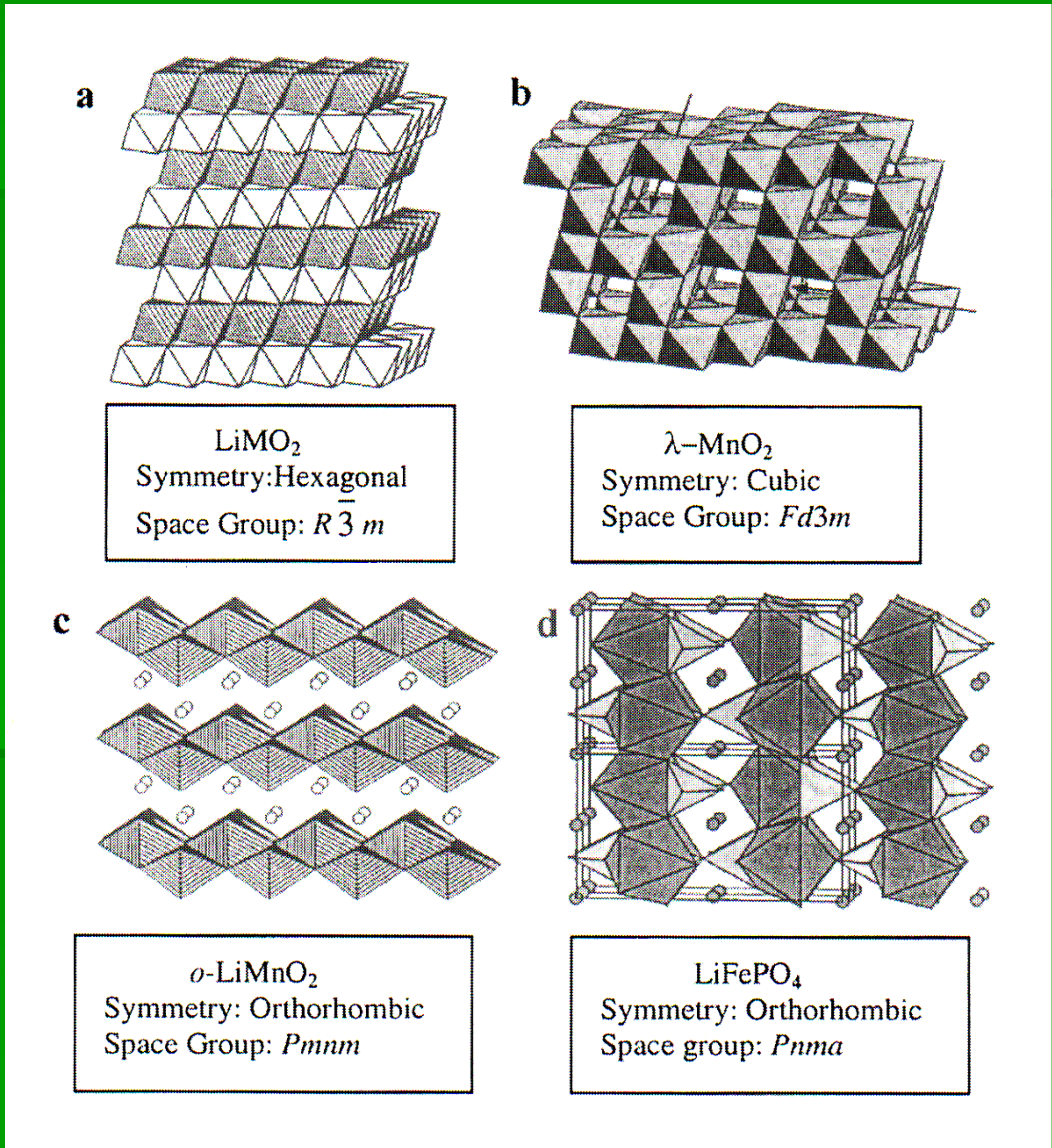


Structure of $Li_{1+x}V_3O_8$.

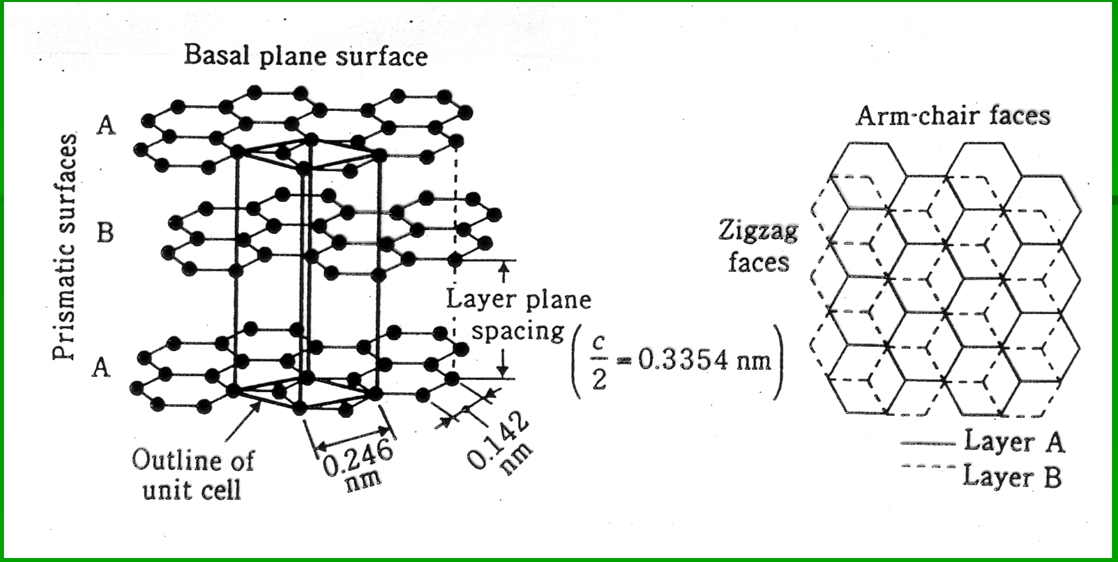



Structure of $V_6O_{13}$.
(Reproduced with permission by D.W. Murphy *et al.*, *J. Electrochem. Soc.*, **126**, 497 (1979))

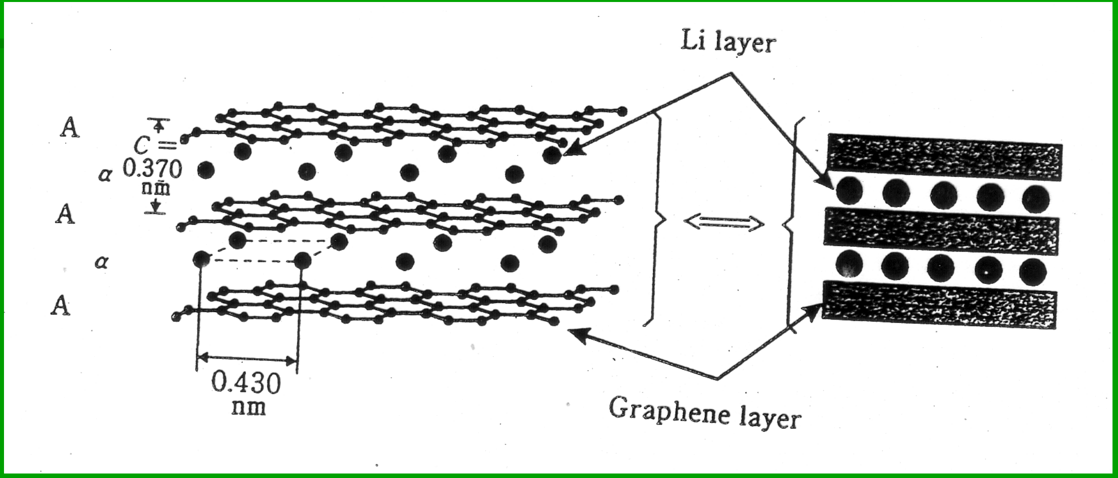
# Strutture dei catodi



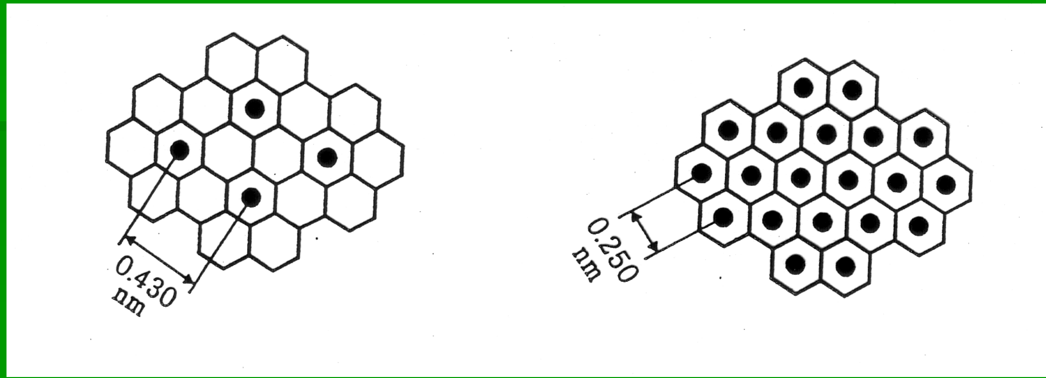
# Struttura della grafite

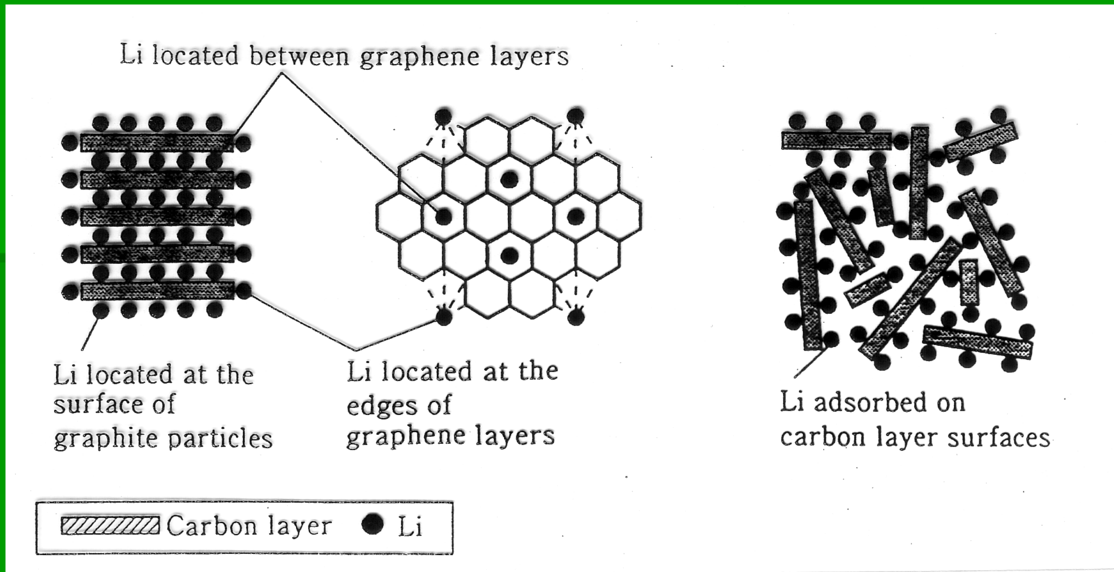


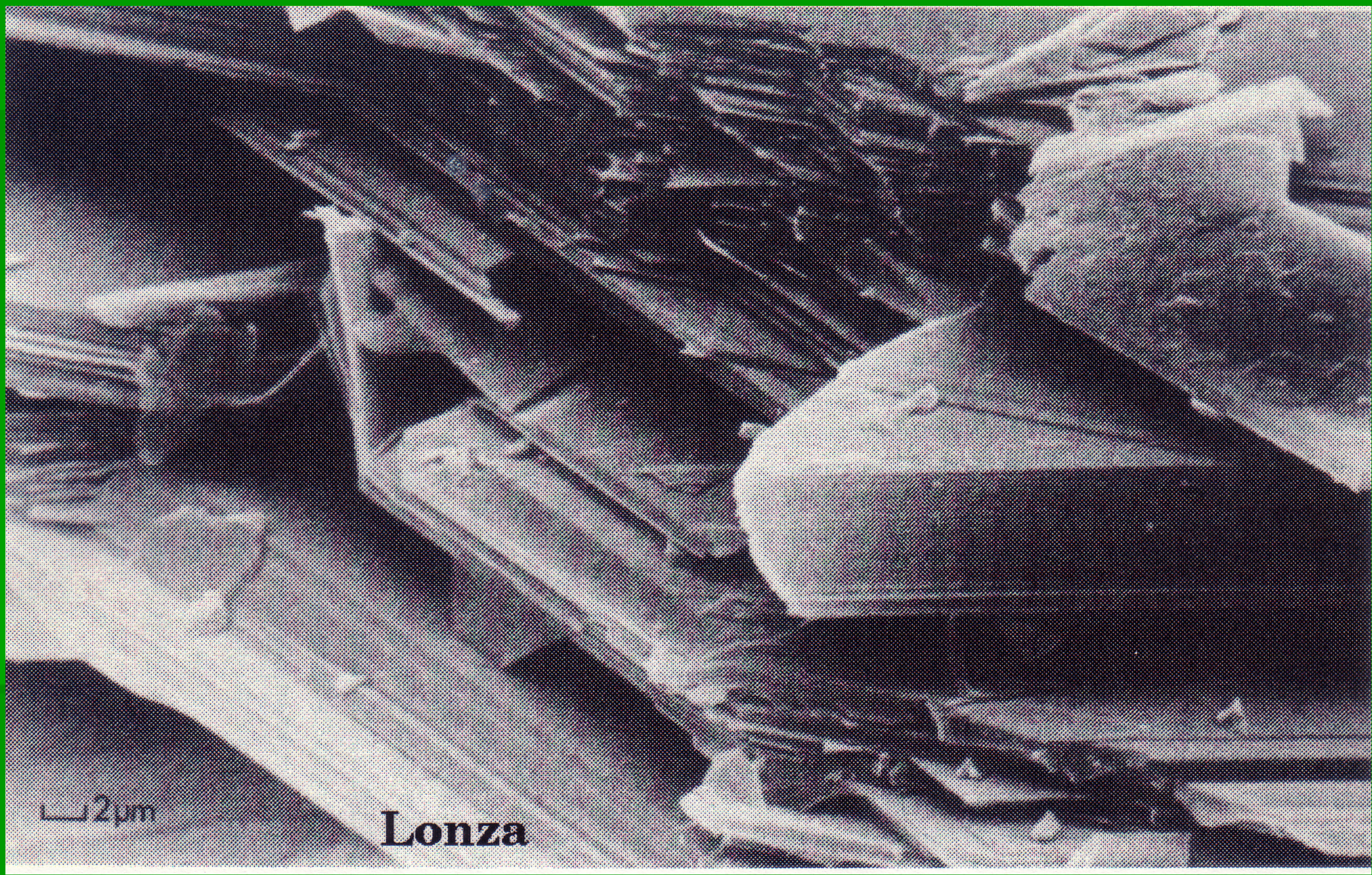

Intercalazione trai piani di grafene

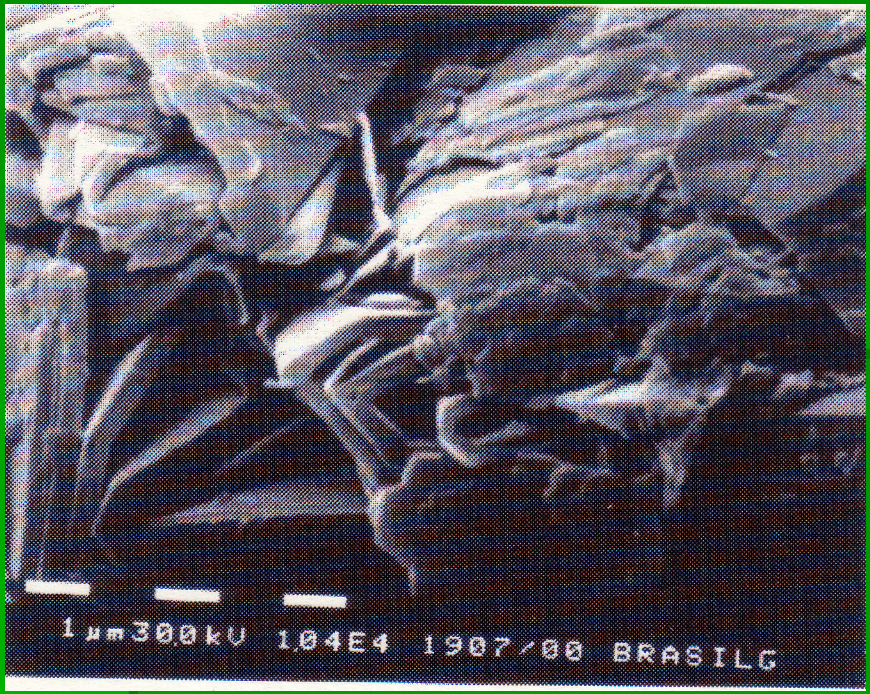


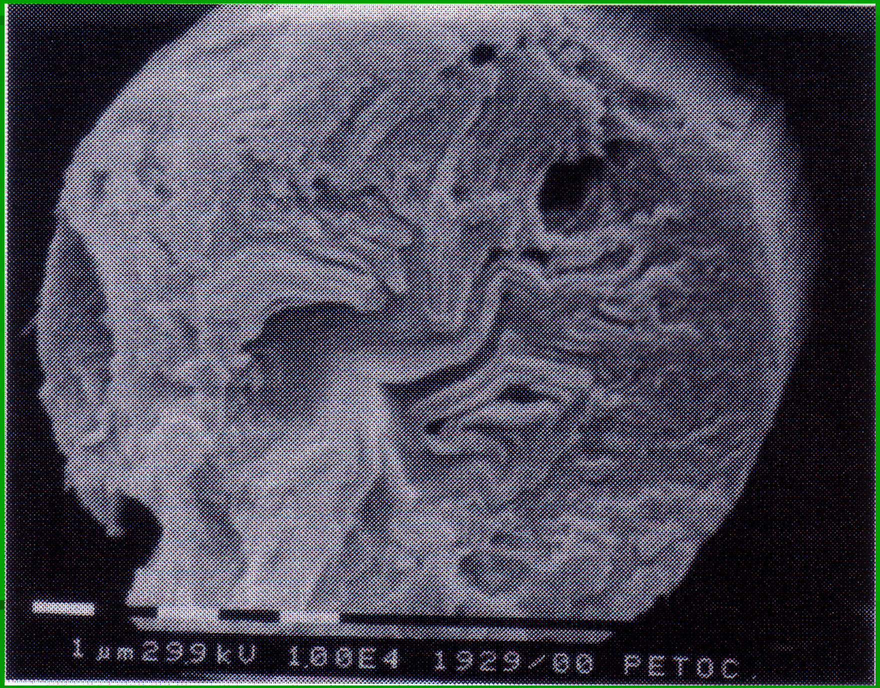
# Struttura della grafite




2µm
Lonza


1 µm 300 kV 1.04E4 1907/00 BRASILG

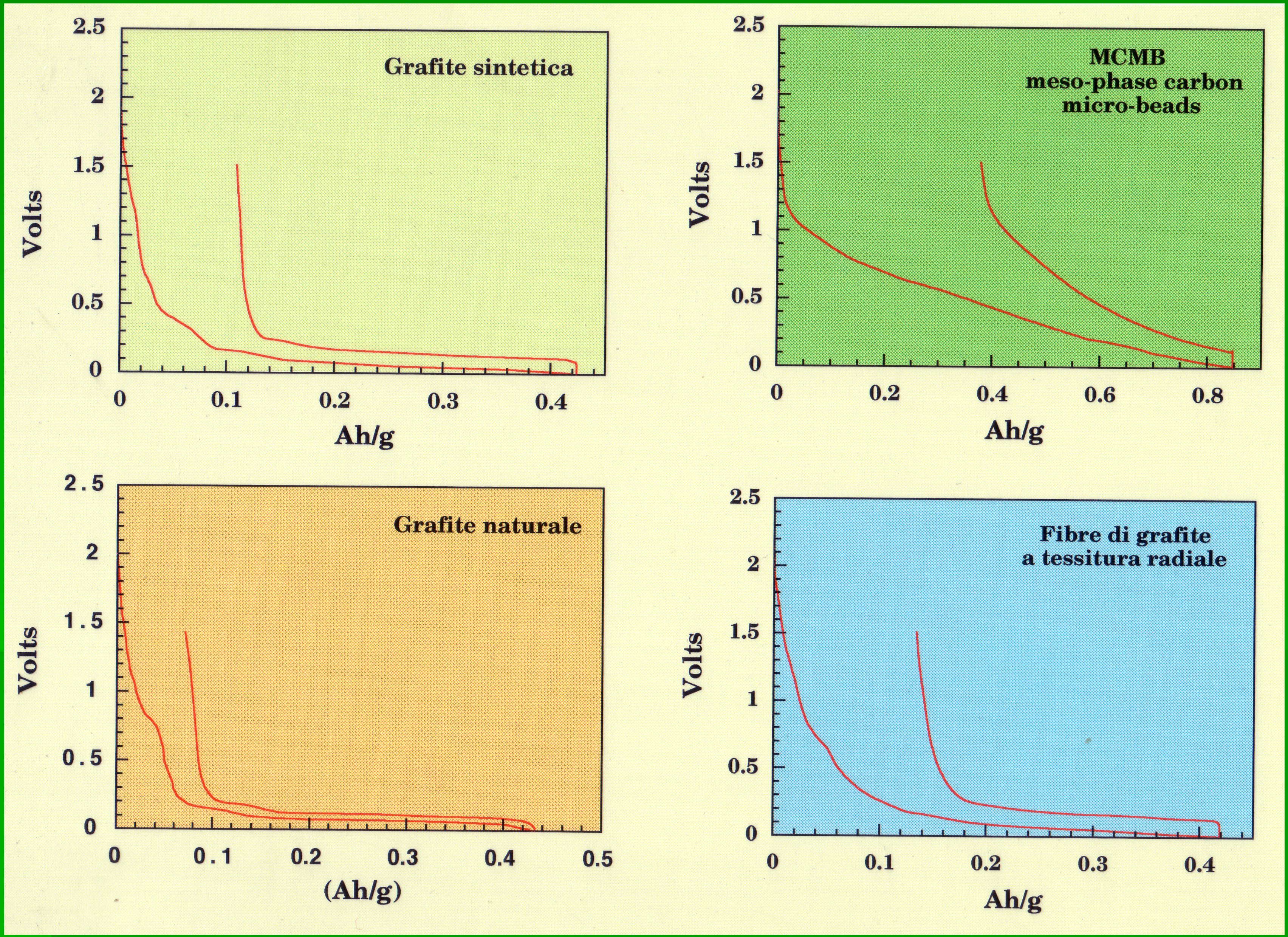

1 µm 299 kV 1.00E4 1929/00 PETOC.


10 µm 299 kV 1.31E3 1928/00 PETOC.

# Caratteristiche dei materiali

| Anodi | Capacità teorica (mAh/g) | Capacità fornita (mAh/g) |
| --- | --- | --- |
| Cokes | 186 | 186 |
| Fibers | 186 | 186 |
| Mesocarbons | 186 | 200 |
| Synthetic Graphites | 372 | 372 |
| Carbons | 372 | 372-500 |
| **Cathodes** | | |
| $LiNiO_2$ | 274 | 137 |
| $LiCoO_2$ | 274 | 137 |
| $LiMn_2O_4$ | 148 | 120 |
| $LiMnO_2$ | 286 | 148 |
| $LiMn_2O_4$ doped (Ti,Al,Co) | 148 | 148 |
| $LiFePO_4$ | 177 | 177 |

# Profili di scarica degli anodi carboniosi



# Profili di scarica dei Catodi

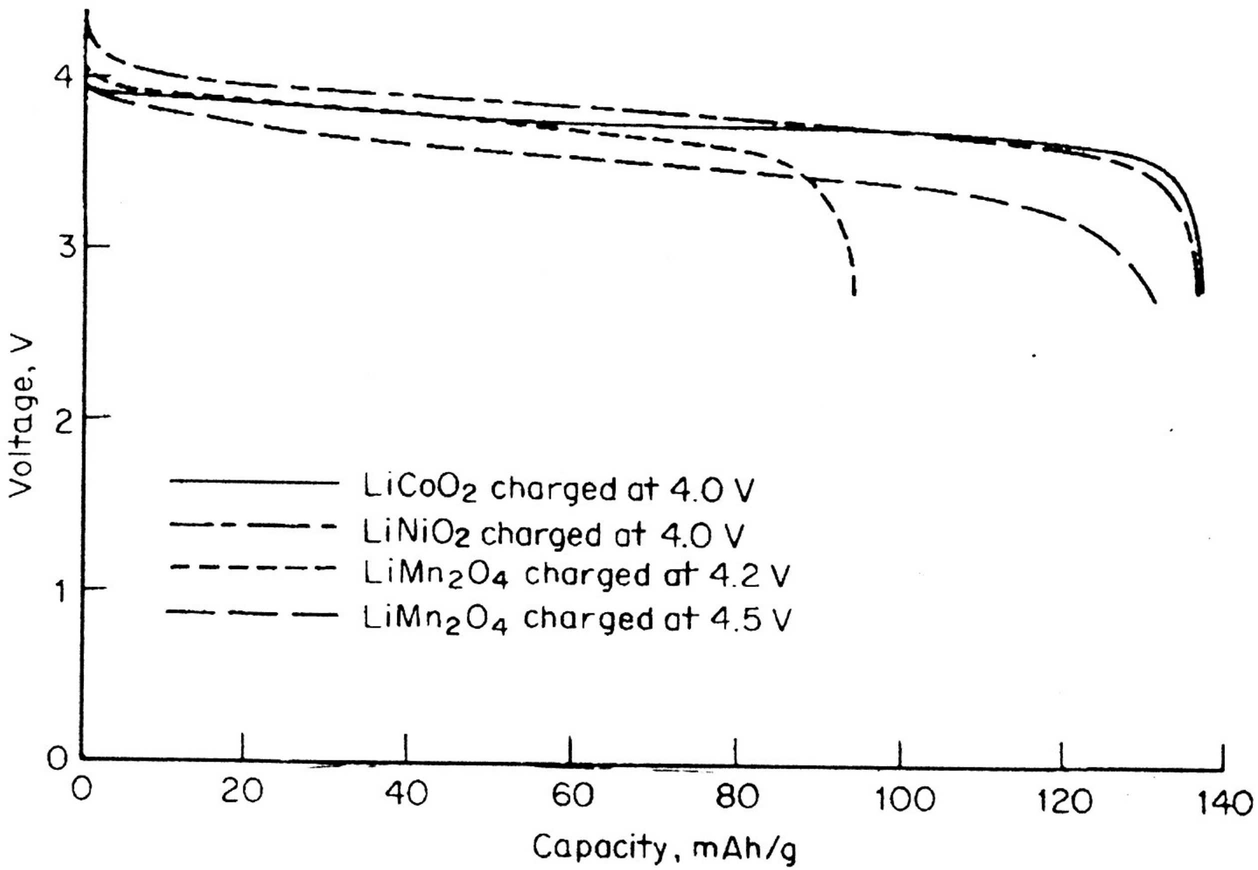
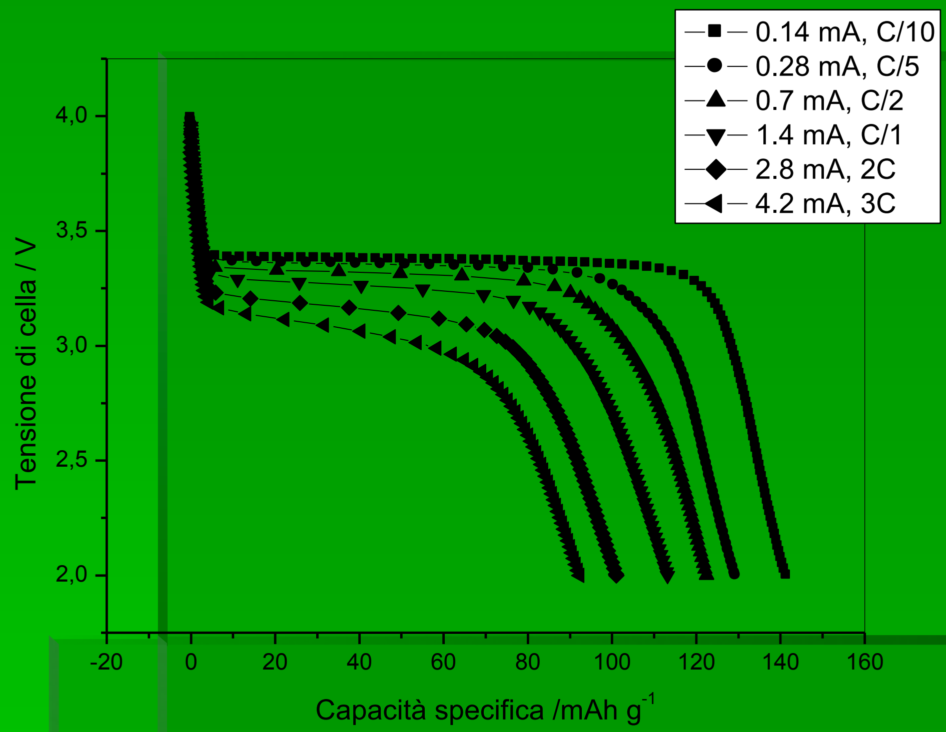
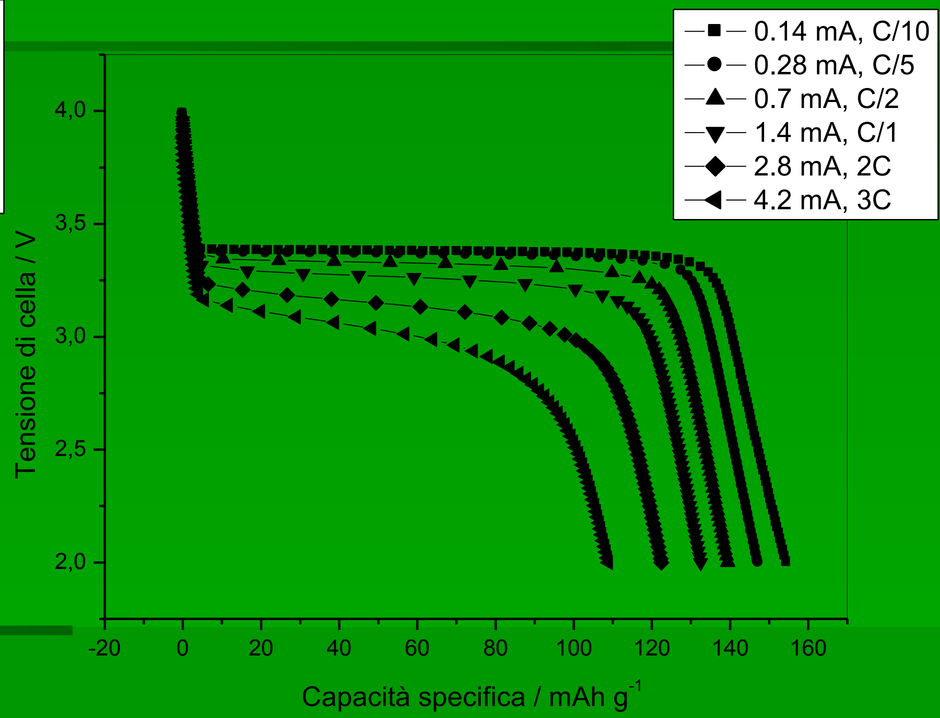



**FIGURE 36.7** Reversible discharge capacity of cathode materials for lithium-ion cells (cells fabricated with graphite anode). (*From Yardney Technical Products, Inc.*)

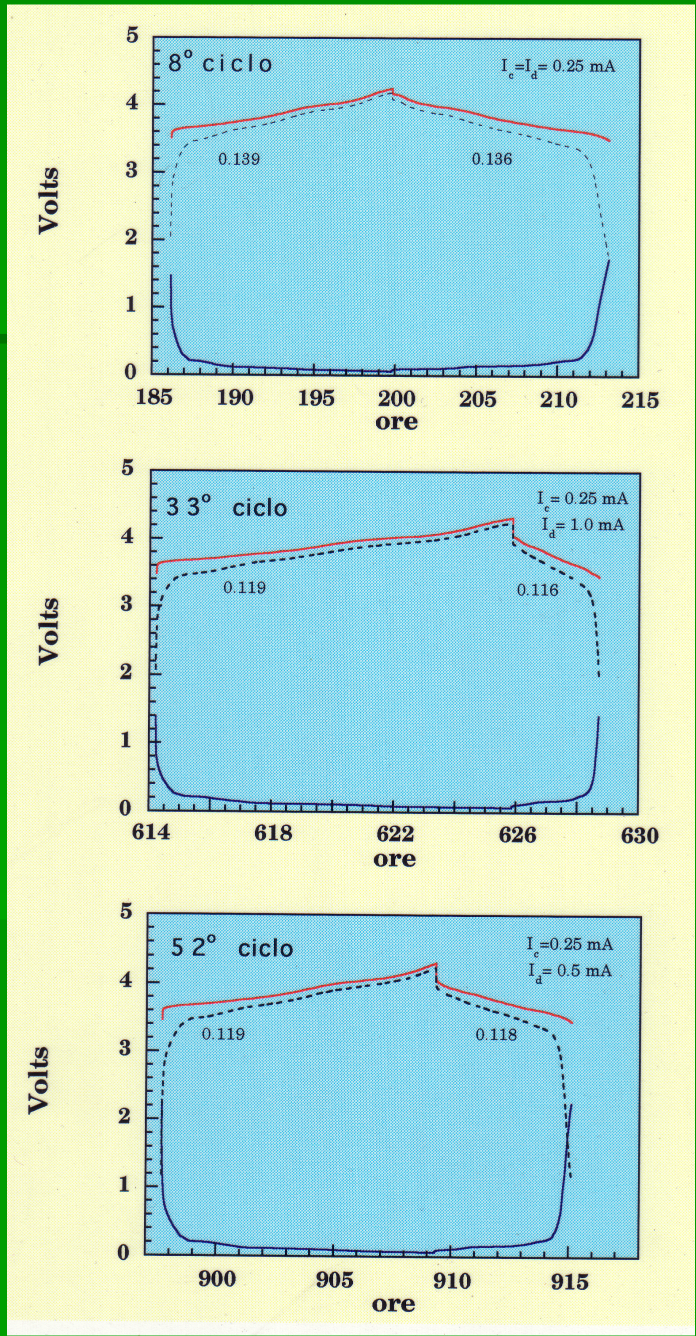
# Profili di scarica del Catodo $LiFePO_4$




Profili di potenziale per EMB-62 (sinistra) e EMB-69 (destra)

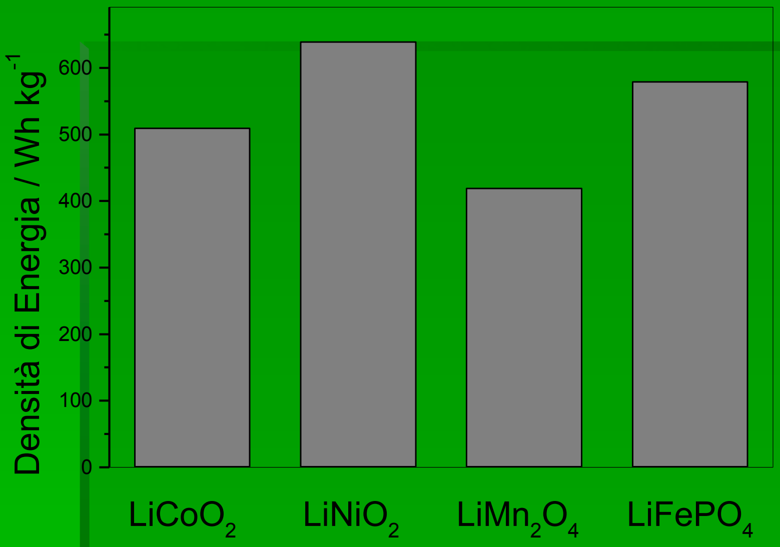
# Profilo di scarica e carica di una cella litio ione

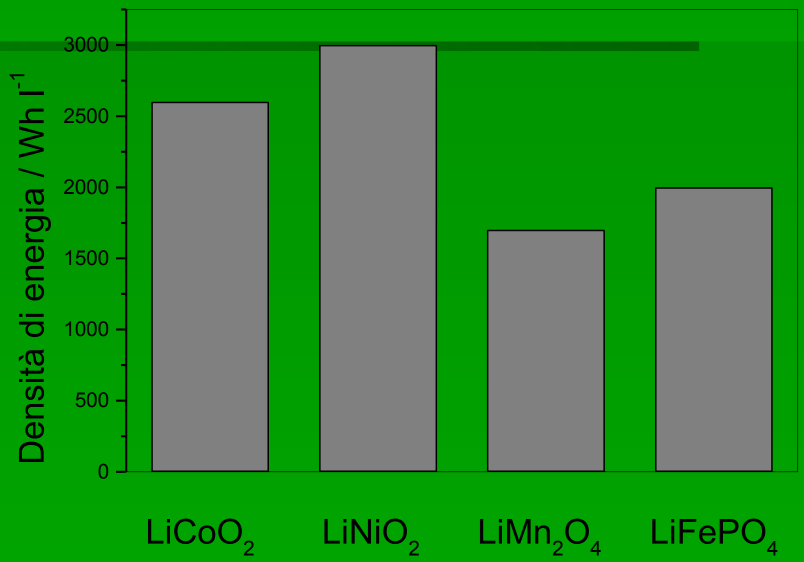


# $Li_{1.02}Mn_{1.95}Cr_{0.01}Ga_{0.04}O_4$

# Materiali catodici per batterie Litio-ione

Poiché il materiale condiziona la chimica della batteria, le conferisce caratteristiche di merito più o meno adatte a differenti applicazioni.




- Basso costo
- Basso impatto ambientale
- LiFePO4 in quanto nanostrutturato presenta un' elevatissima area superficiale che rende possibili intensità di corrente molto alte.

**$LiFePO_4$ è adatto a batterie per elevate potenze del tipo per autoveicoli HEV e EV**

# Tipi di pile

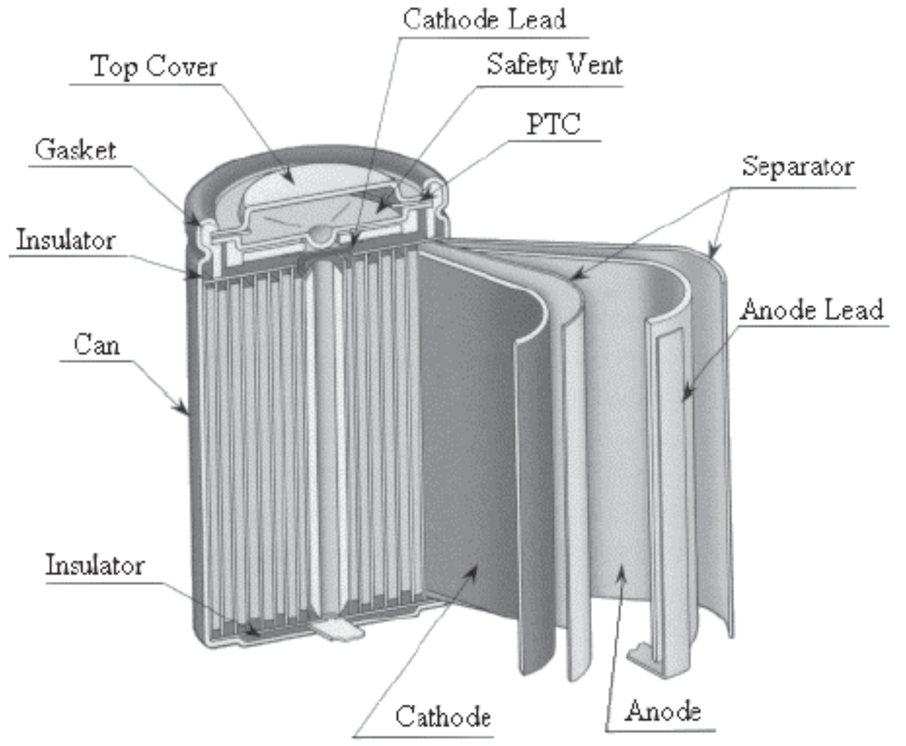



**FIGURE** Cross-sectional view of a cylindrical Li-ion cell.

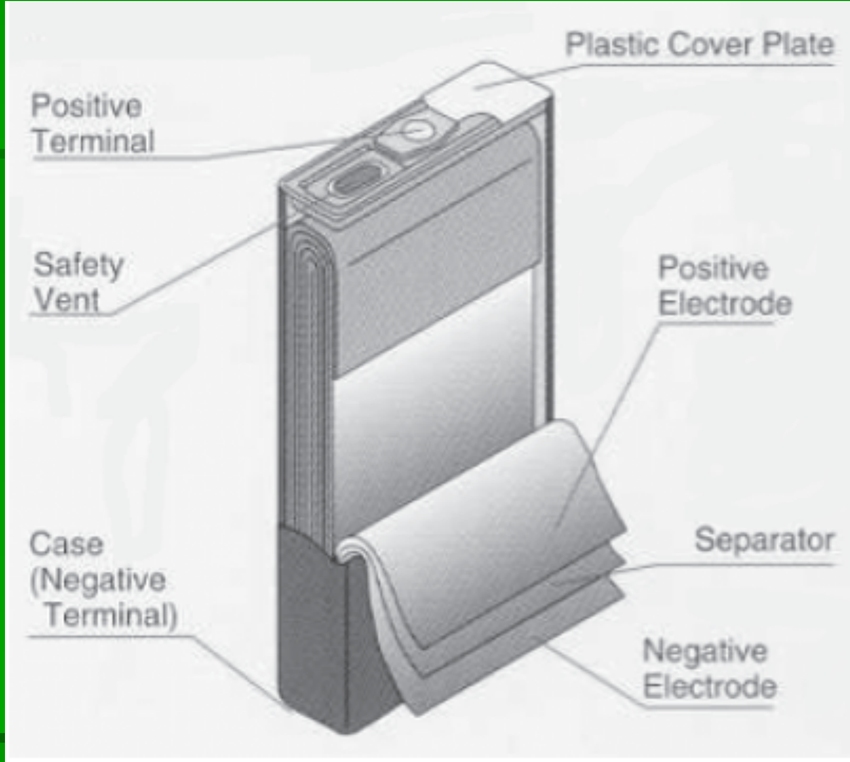



**FIGURE** Schematic drawing of a wound prismatic cell.

# Assemblaggio delle pile

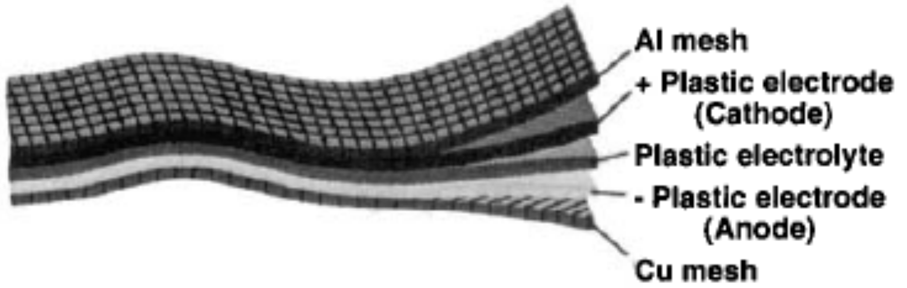



**FIGURE** Schematic diagram showing the construction of a polymer Li-ion cell.

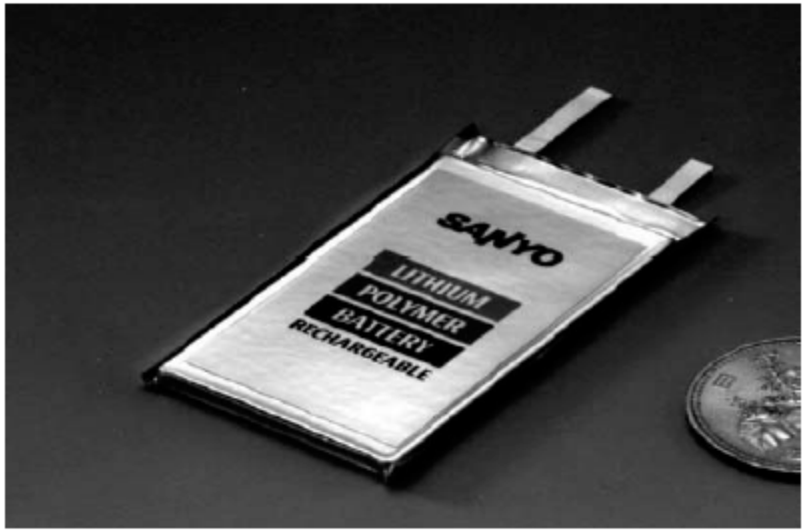



**FIGURE** A 0.57 Ah polymer Li-ion battery.

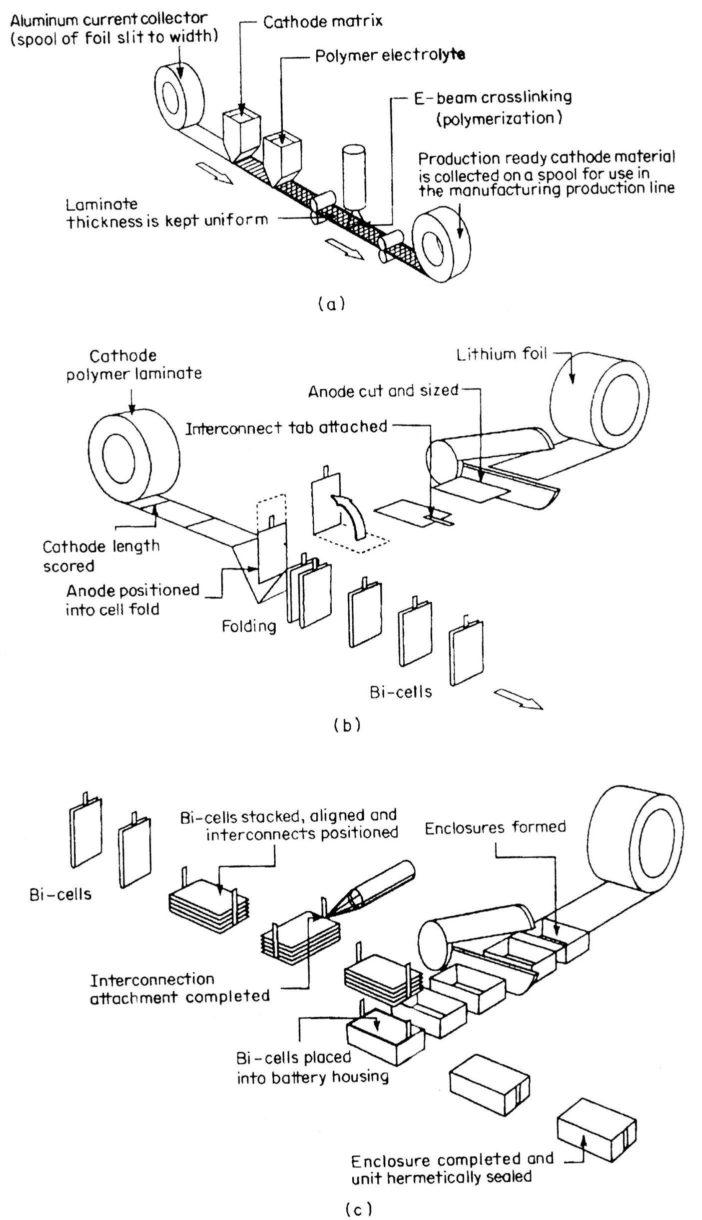



**FIGURE 36.28** Assembly process for a SPE battery. (*a*) Laminate production process. (*b*) Bi-cell assembly. (*c*) Battery assembly. *(From Valence Technology, Inc.)*

# Dispositivi di sicurezza

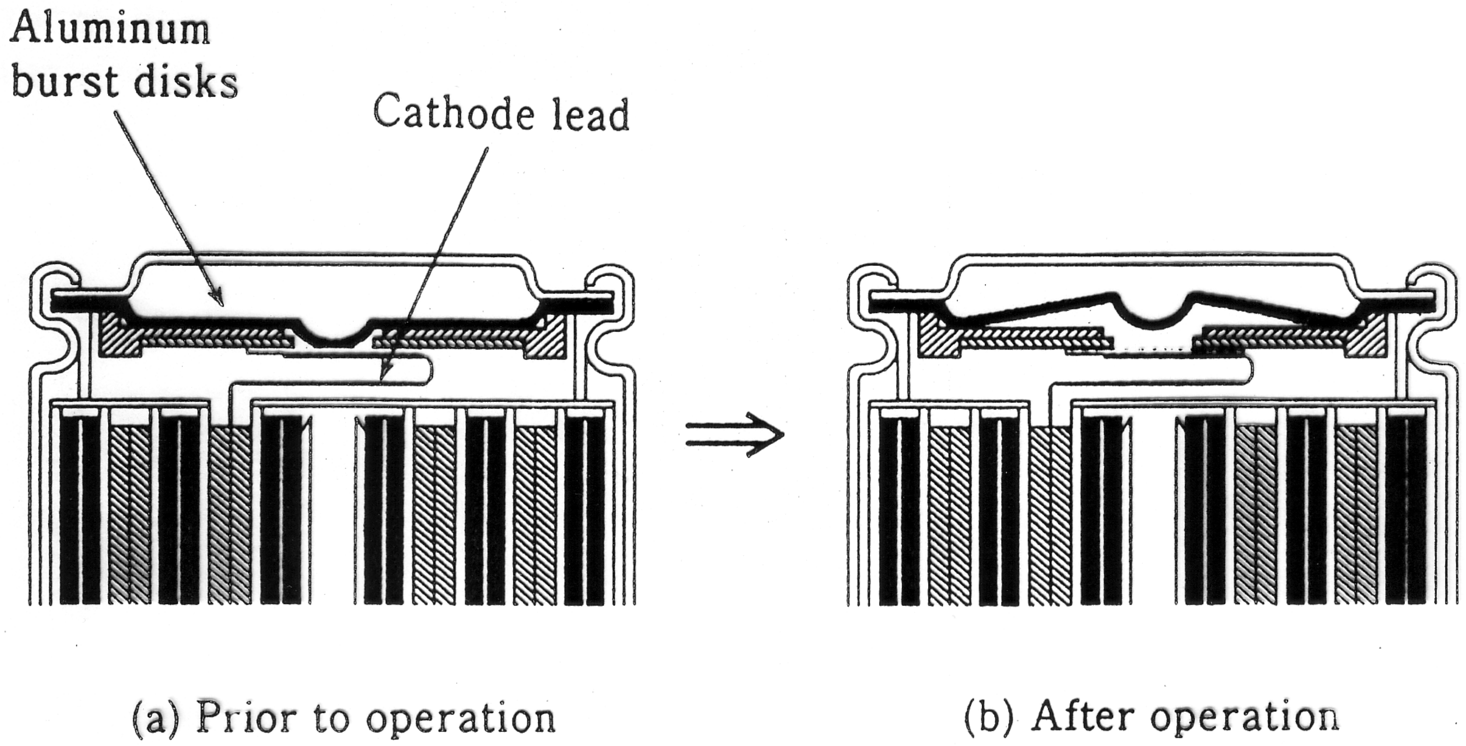



Fig. Safety device which operates on internal pressure build-up in cells.