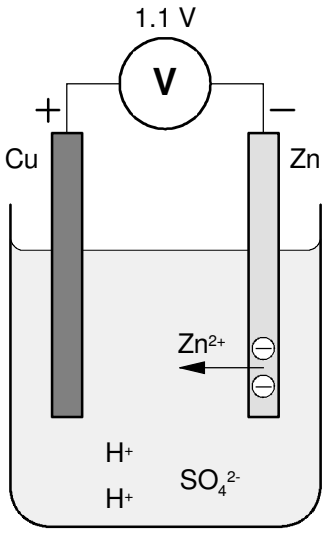
**ELEKTROKEMIJSKI IZVORI** – energija oslobođena kemijskom reakcijom izravno se pretvara u električnu energiju.

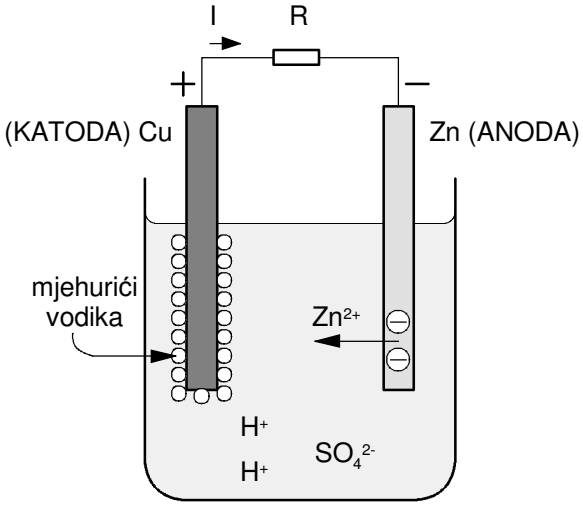
1. **BATERIJE** – primarni izvori (*engl. primary batteries*): životni vijek se završava potrošnjom reaktanata tijekom procesa pražnjenja.
2. **AKUMULATORI** – Sekundarni izvori (engl. *rechargeable batteries*): imaju mogućnost ponovnog punjenja.

**VOLTIN ČLANAK**: ako u elektrolit uronimo dvije pločice od različitih metala, između njih se javlja razlika potencijala.




**ELEKTROKEMIJSKI NIZ** (Voltin niz): potencijal pojedinog metala prema standardnoj vodikovoj elektrodi:

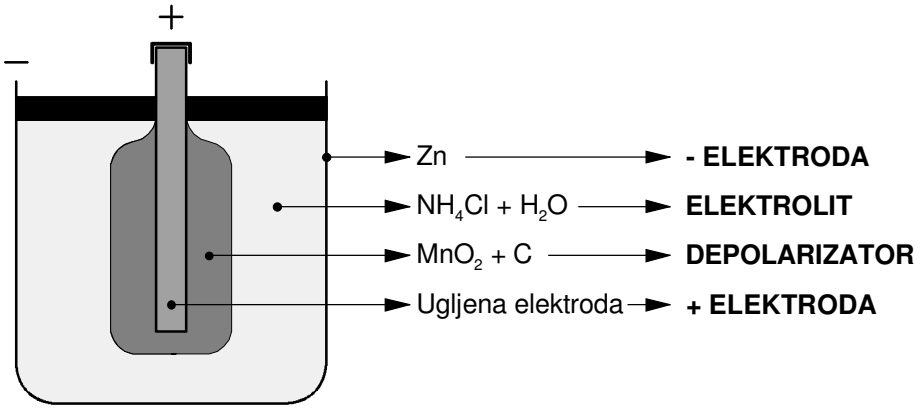
| Au | Ag | Cu | **H** | Pb | Sn | Ni | Cd | Fe | Cr | Zn | Al | Na | Li |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| +1.36 | +0.80 | +0.34 | **0** | –0.13 | –0.14 | –0.23 | –0.40 | –0.44 | –0.56 | –0.76 | –1.28 | –2.71 | –3.05 |




**KATODA:** Elektroda prema kojoj se elektroni kreću iz vanjskog kruga (elektroda na kojoj se odigrava **redukcija**).

**ANODA:** Elektroda iz koje elektroni kreću u vanjski krug (elektroda na kojoj se odigrava **oksidacija**).

**LECLANCHÉov ČLANAK** – CINK-UGLJIK (*engl. zinc-carbon*)




Opis članka:

| $Zn(s)$ | $ZnCl_2(aq), NH_4Cl(aq)$ | $MnO_2(s), C(s)$ |
|---|---|---|
| - | elektrolit | depolarizator, + |

Napon praznog hoda (*engl. open circuit voltage*): 1.5 – 1.7 V

## ALKALIJSKI MANGANOVI ELEMENTI (0% Hg, 0% Cd)

Elektrolit je lužina (baza) (*engl. alkali*)

Opis članka:

| $Zn(s)$ | $ZnO(s)$ | $KOH(aq)$ | $MnO_2(s), C(s)$ |
|---|---|---|---|
| - | elektrolit | | depolarizator, + |

Reakcija: $Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$

Nominalni napon: 1.5 V
Kapacitet: "button" 45 mAh ÷ 110 mAh
cilindrične 580 mAh ÷ 15000 mAh
Temperaturno područje: -20°C ÷ +54°C
Unutarnji otpor: < 1 Ω, konstantan tijekom životnog vijeka
Specifična energija: 130 Wh/kg
320 Wh/$dm^3$
Vrijeme skladištenja (*engl. shelf time*): nakon 1 godine zadržava 93 ÷ 96% kapaciteta
nakon 4 godine zadržava 85% kapaciteta

## **ŽIVINA BATERIJA** – CINK-ŽIVIN OKSID (*Ruben-Mallory Cell, 1940*)

Opis članka:

| Zn(s) | ZnO(s) | KOH(aq) | HgO(s), C(s) |
|---|---|---|---|
| - | | elektrolit | depolarizator, + |

Reakcija: $Zn(s) + HgO(s) \rightarrow ZnO(s) + Hg(l)$

Napon praznog hoda: 1.35 V
Specifični kapacitet: 400 $Ah/dm^3$
Specifična energija: 550 $Wh/dm^3$
Vrijeme skladištenja: nakon 1 godine zadržava više od 90% početnog kapaciteta
Kratki spoj ne uništava bateriju, vrijeme oporavka je vrlo brzo.
Nije pogodna za niske temperature.

## **CINK – SREBRNI OKSID**

Opis članka:

| Zn(s) | ZnO(s) | KOH(aq) | $Ag_2O(s)$, C(s) |
|---|---|---|---|
| - | | elektrolit | depolarizator, + |

Reakcija: $Zn(s) + Ag_2O(s) \rightarrow ZnO(s) + 2Ag(s)$

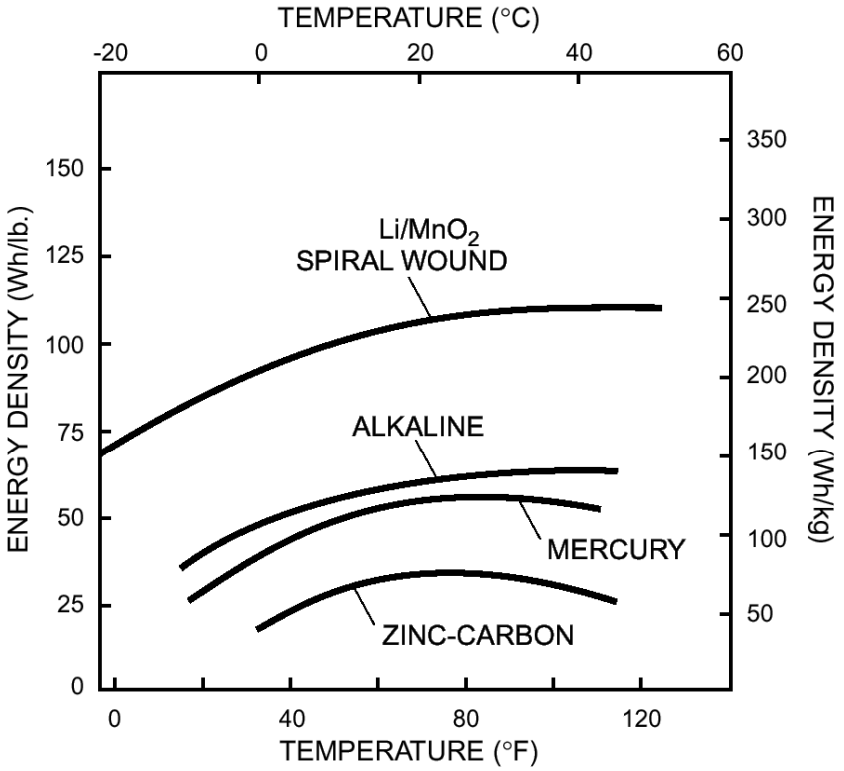
Veći nominalni napon od živinih baterija: 1.6 V
Temperaturno područje: -20°C ÷ +50°C
Specifična energija: 130 Wh/kg
500 $Wh/dm^3$
Vrijeme skladištenja: nakon 2 godine skladištenja (na 21°C) zadržava 84% početnog kapaciteta

## **LITIJEVE BATERIJE –** familija baterija koje koriste litij kao anodu

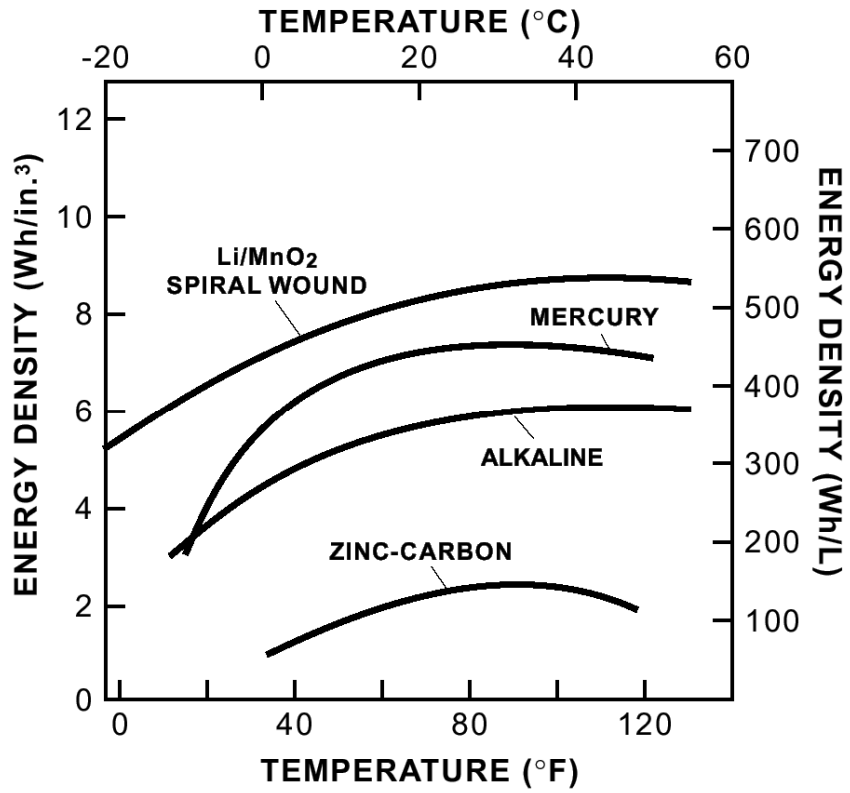
| Materijal anode | Atomska težina | Ah/g |
|---|---|---|
| Pb | 207.19 | 0.26 |
| Zn | 65.37 | 0.82 |
| Fe | 55.85 | 0.96 |
| **Li** | **6.94** | **3.86** |

Litij je najlakši od svih metala, ima najveći elektrodni potencijal i njegove baterije imaju najveći specifični kapacitet.

Nominalni napon: 3 V
Unutarnja impedancija: 10 Ω @ 1 kHz, pada s povećanjem dimenzija
Temperaturno područje: optimalno -20°C ÷ +60°C
može i od -40°C ÷ +70°C
Specifična energija: 270 Wh/kg
690 $Wh/dm^3$
Vrijeme skladištenja: nakon 5 godine skladištenja (na 21°C) zadržava 97% početnog kapaciteta

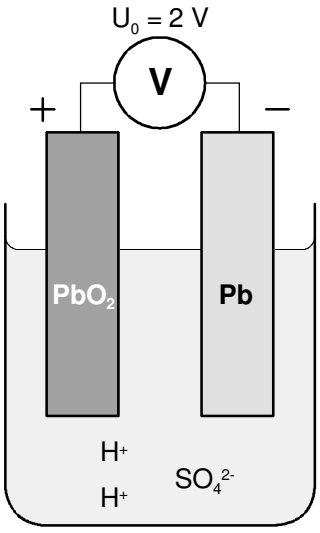



Gravimetric energy density comparison of primary cylindrical cells.




Volumetric energy density comparison of primary cylindrical cells.

## OLOVNI AKUMULATOR




Reakcija:

$$Pb + PbO_2 + 2H_2SO_4 \underset{\text{punjenje}}{\overset{\text{pražnjenje}}{\rightleftarrows}} PbSO_4 + PbSO_4 + 2H_2O$$

Napon pune ćelije u praznom hodu: 2.2 V
Nominalni napon jedne ćelije: 2 V
Preporučeni najniži napon jedne ćelije: 1.83 V
Preporučeni najviši napon pri punjenju: 2.7 V

## **KADMIJ-NIKAL OKSID AKUMULATORI** (NIKAL-KADMIJ AKUMULATORI, NiCd)

Reakcija:

$$2NiOOH + Cd + 2H_2O \underset{\text{punjenje}}{\overset{\text{pražnjenje}}{\rightleftarrows}} 2Ni(OH)_2 + Cd(OH)_2$$

Napon praznog hoda: 1.28 ÷ 1.35 V, nominalni 1.2 V
500 ciklusa punjenja-pražnjenja
Specifična energija: 21 ÷ 27 Wh/kg
42 ÷ 78 Wh /$dm^3$
Prazni se do napona 1 V
Puni se do napona 1.45 V
Nominalni kapacitet: količina naboja koja se isporuči za 5 sati pražnjenja strujom od 0.2 C do napona 1 V na 20°C

## **NIKAL – METAL HIDRID AKUMULATORI** (NiMH)

Reakcija:

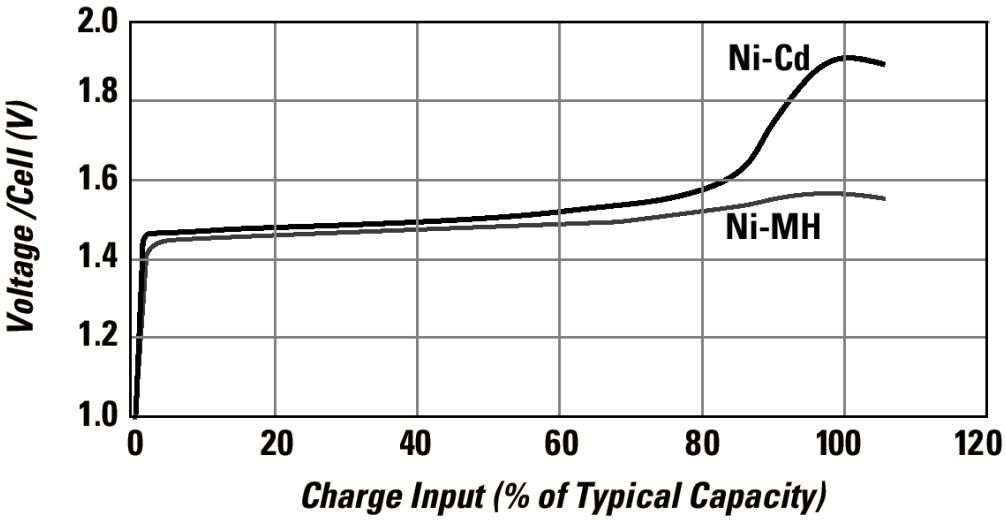
$$MH + NiOOH \underset{\text{punjenje}}{\overset{\text{pražnjenje}}{\rightleftarrows}} M + Ni(OH)_2$$

"Metal" je slitina koja ima mogućnost pohranjivanja vodika velike volumne gustoće.

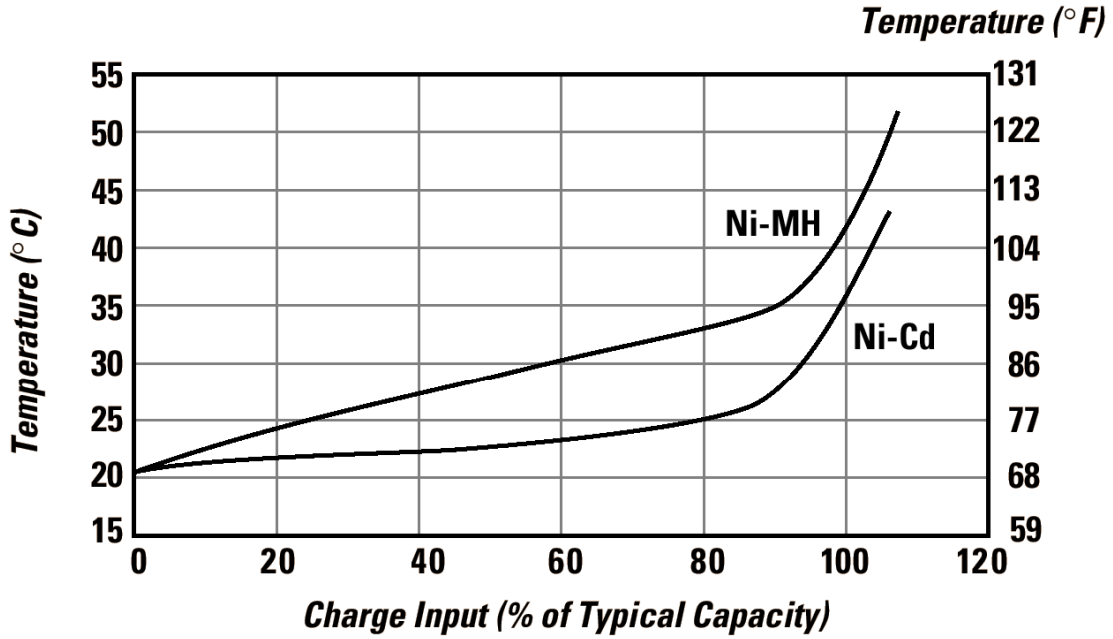
Postoje dvije izvedbe: 1. $AB_5$ $LaNi_5$
2. $AB_2$ $TiMn_2$, $ZrMn_2$

Slični su po karakteristikama NiCd akumulatorima, ali imaju veći kapacitet i do 40%
Dozvoljava brzo punjenje: za 1 sat
Napon praznog hoda: 1.28 ÷ 1.35 V, nominalni 1.2 V
500 ciklusa punjenja-pražnjenja
Specifična energija: 65 Wh/kg
175 Wh/$dm^3$
Prazni se do napona 1 V
Mali unutarnji otpor: 0.17 ÷ 0.175 Ω, ovisno o stupnju ispražnjenosti
Podnosi jake struje pražnjenja: do 2 C

**KRIVULJE PUNJENJA NiCd i NiMH akumulatora**



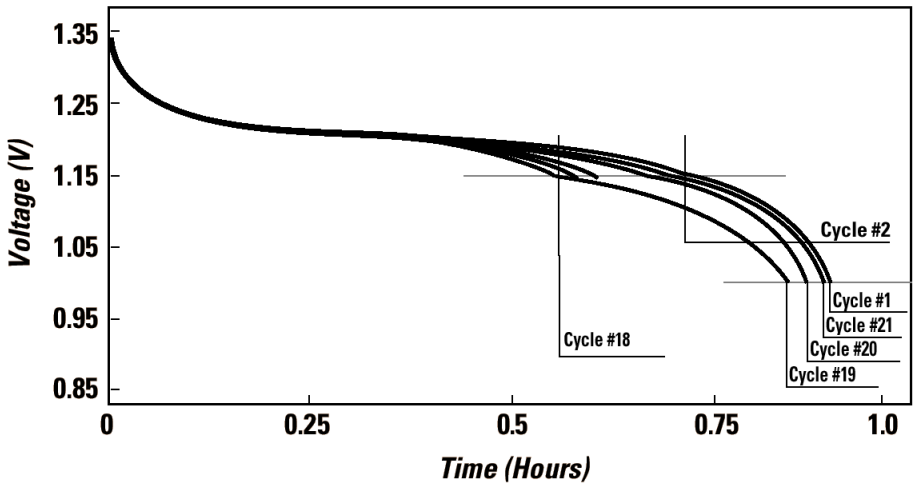

Typical charge voltage characteristics of Ni-MH and Ni-Cd batteries.
[Conditions: Charge: 1C @ 21°C (70°F) to -ΔV = 10mV/cell]




Typical charge temperature characteristics of Ni-MH and Ni-Cd batteries.
[Conditions: Charge: 1C @ 21°C (70°F) to -ΔV = 10mV/cell]

## Voltage Depression ("Memory Effect")

Although many years of premium performance can be enjoyed from a nickel-metal hydride battery that is properly handled, the capacity delivered in each charge/discharge cycle will eventually begin to decrease. This inevitable decrease in capacity can be accelerated by overcharging, storage or usage at high temperatures, or through poor matching of cells within a pack. Often, battery users who experience short service life have incorrectly attributed capacity loss to a phenomenon called "memory effect." The term memory effect is used synonymously with the term "voltage depression." Voltage depression is a scientifically measurable characteristic of all batteries, however, nickel-cadmium batteries demonstrate particularly acute sensitivity. A properly designed application with nickel-metal hydride batteries will result in neither permanent performance loss nor perceivable temporary capacity decreases from this characteristic. A reversible drop in voltage and loss of capacity may occur when a nickel-metal hydride battery is partially discharged and recharged repetitively without the benefit of a full discharge, as illustrated in Figure. After an initial full discharge (Cycle #1) and charge, the cell is partially discharged to 1.15 volts and recharged for a number of cycles. During this cycling, the discharge voltage and capacity drop gradually in very small increments (Cycles #2 to #18). On a subsequent full discharge (Cycle #19), the discharge voltage is depressed compared to the original full discharge (Cycle #1). Because the cell appears to "remember" the lower capacity, this voltage depression phenomenon is often referred to as memory effect. However, the cell can be quickly restored to full capacity with a few full discharge/charge cycles, as indicated in Cycles #20 and #21. The voltage drop occurs because only a portion of the active materials in the cell is discharged and recharged during shallow or partial discharging. The active materials that have not been cycled change in physical characteristics and increase in resistance. Subsequent full discharge/charge cycling will restore the active materials to their original state. The extent of voltage depression and capacity loss depends on depth of discharge and can be avoided by discharging the battery to an appropriate cut-off voltage. Voltage depression is most apparent when the discharge is terminated at higher cut-off voltages, such as 1.2 volts per cell. A smaller voltage depression and capacity loss occurs if the discharge is cut off between 1.15 volts to 1.10 volts per cell. Discharging to 1.0 volts per cell should not result in significant voltage depression or capacity loss during subsequent discharges. A device properly designed with nickel-metal hydride batteries will minimise the effects of voltage depression and capacity loss. The voltage depression and capacity loss in DURACELL nickel-metal hydride batteries is only a small fraction (less than 5 percent in worst cases) of the battery's capacity and most users will never experience a perceptible performance loss.




Effects on Ni-MH cell capacity due to repetitive partial discharges.

[Conditions: Charge: (Cycle #1– #21) = 1C to -ΔV = 12mV. Discharge: Cycle #1 = 1C to 1.0 V, (Cycle #2– #18) = 1C to 1.15V, (Cycle #19 – #21) = 1C to 1.0V; Temperature: 21°C (70°F)]