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Zinc–carbon battery

A **zinc–carbon battery** is a dry cell primary battery that delivers about 1.5 volts of direct current from the electrochemical reaction between zinc and manganese dioxide. A carbon rod collects the current from the manganese dioxide electrode, giving the name to the cell. A dry cell is usually made from zinc, which serves as the anode with a negative electrical polarity, while the inert carbon rod is the positive electrical pole cathode. General-purpose batteries may use an aqueous paste of ammonium chloride as electrolyte, possibly mixed with some zinc chloride solution. *Heavy-duty* types use a paste primarily composed of zinc chloride.

Zinc–carbon batteries of various sizes

Zinc–carbon batteries were the first commercial dry batteries, developed from the technology of the wet Leclanché cell. They made flashlights and other portable devices possible, because the battery can function in any orientation. They are still useful in low drain or intermittent use devices such as remote controls, flashlights, clocks or transistor radios. Zinc–carbon dry cells are single-use primary cells.

Contents

History

By 1876, the wet Leclanché cell was made with a compressed block of manganese dioxide. In 1886, Carl Gassner patented a "dry" version by using a zinc cup as the anode and a paste of plaster of Paris (and later, wheat flour) to jellify the electrolyte and to immobilize it.

Old 3 V zinc–carbon battery (around 1960), with cardboard casing

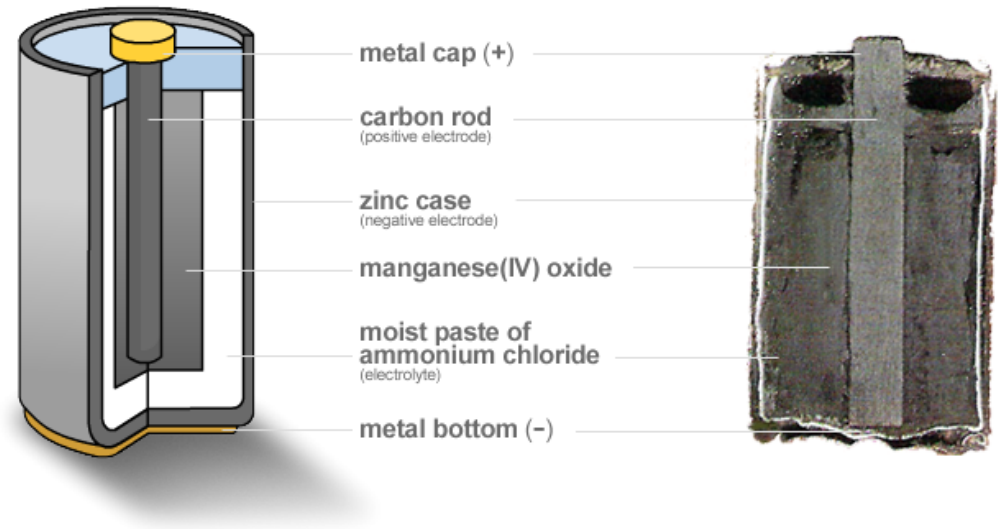
In 1898, Conrad Hubert used consumer batteries manufactured by W. H. Lawrence to power what was the first flashlight, and subsequently the two formed the Eveready Battery Company. In 1900, Gassner demonstrated dry cells for portable lighting at the World's Fair in Paris. Continual improvements were made to the stability and capacity of zinc–carbon cells throughout the 20th century; by the end of the century the capacities had increased fourfold over the 1910 equivalent.[1] Improvements include the use of purer grades of manganese dioxide, better sealing, and purer zinc for the negative electrode. Zinc-chloride cells (usually marketed as "heavy duty" batteries) use a paste primarily composed of zinc chloride, which gives a longer life and steadier voltage output compared with ammonium chloride electrolyte.

Side reactions due to impurities in the zinc anode increase self-discharge and corrosion of the cell. Formerly, the zinc was coated with mercury to form an amalgam, protecting it. Since this is an environmental hazard, current production batteries no longer use mercury. Manufacturers must now use more highly purified zinc to prevent local action and self-discharge.[1]

As of 2011, zinc–carbon batteries accounted for 20% of all portable batteries in the UK and 18% in the EU.[2][3][4][5] In Japan they account for 6% of primary battery sales.

Construction

The container of the zinc–carbon dry cell is a zinc can. The can contains a layer of NH_4Cl or $ZnCl_2$ aqueous paste impregnating a paper layer that separates the zinc can from a mixture of powdered carbon (usually graphite powder) and manganese (IV) oxide (MnO_2), which is packed around a carbon rod. Carbon is the only practical conductor material because every common metal quickly corrodes in the positive electrode in salt-based electrolyte.



Cross-section of a zinc–carbon battery

Early types, and low-cost cells, use a separator consisting of a layer of starch or flour. A layer of starch-coated paper is used in modern cells, which is thinner and allows more manganese dioxide to be used. Originally cells were sealed with a layer of asphalt to prevent drying out of the electrolyte; more recently a thermoplastic washer sealant is used. The carbon rod is slightly porous, which allows accumulated hydrogen gas to escape, while retaining the aqueous electrolyte. The ratio of manganese dioxide and carbon powder in the cathode paste affects the characteristics of the cell: more carbon powder lowers internal resistance, while more manganese dioxide improves storage capacity.[1]

Flat cells are made for assembly into batteries with higher voltages, up to about 450 volts. Flat cells are stacked and the whole assembly is coated in wax to prevent electrolyte evaporation.

Chemical reactions

In a zinc–carbon dry cell, the outer zinc container is the negatively charged terminal. The zinc is oxidised by the charge carrier, chloride (Cl^-) via the following half reactions:

Anode (oxidation reaction, marked –)

$$Zn + 2\ Cl^- \rightarrow ZnCl_2 + 2\ e^-$$

Cathode (reduction reaction, marked +)

$$2\ MnO_2 + 2\ NH_4Cl + H_2O + 2\ e^- \rightarrow Mn_2O_3 + 2\ NH_4OH + 2\ Cl^-$$

Other side reactions are possible, but the overall reaction in a zinc–carbon cell can be represented as

$$Zn + 2\ MnO_2 + 2\ NH_4Cl + H_2O \rightarrow ZnCl_2 + Mn_2O_3 + 2\ NH_4OH$$

If zinc chloride is substituted for ammonium chloride as the electrolyte, the anode reaction remains the same:

$$Zn + 2\ Cl^- \rightarrow ZnCl_2 + 2\ e^-$$

and the cathode reaction produces zinc hydroxide instead of ammonium hydroxide:

$$2\ MnO_2 + ZnCl_2 + H_2O + 2\ e^- \rightarrow Mn_2O_3 + Zn(OH)_2 + 2\ Cl^-$$

giving the overall reaction

$$Zn + 2\ MnO_2 + H_2O \rightarrow Mn_2O_3 + Zn(OH)_2$$

The battery has an electromotive force (e.m.f.) of about 1.5 V. The approximate nature of the e.m.f is related to the complexity of the cathode reaction. The anode (zinc) reaction is comparatively simple with a known potential. Side reactions and depletion of the active chemicals increases the internal resistance of the battery, which causes the terminal voltage to drop under load.

Zinc-chloride "heavy duty" cell

The zinc-chloride cell, frequently referred to as a *heavy-duty*, *extra-heavy-duty*, or even *super-heavy-duty* battery, is an improvement on the original zinc–carbon cell, using purer chemicals and giving a longer service life and steadier voltage output as it is used and offering about twice the service life of general-purpose zinc–carbon cells, or up to four times in continuous-use or high-drain applications.[1] This is still a fraction of the output of an alkaline cell, however.

Alkaline batteries[6] offer up to eight times the battery life of zinc–carbon batteries,[7] especially in continuous-use or high-drain applications.[1]

Storage

Manufacturers recommend storage of zinc–carbon batteries at room temperature; storage at higher temperatures reduces the expected service life.[8] Zinc–carbon batteries may be frozen without damage; manufacturers recommend that they be returned to normal room temperature before use, and that condensation on the battery jacket must be avoided. By the end of the 20th century, the storage life of zinc–carbon cells had improved fourfold over expected life in 1910.[1]

Durability

Zinc–carbon cells have a short shelf life, as the zinc is attacked by ammonium chloride. The zinc container becomes thinner as the cell is used, because zinc metal is oxidized to zinc ions. When the zinc case thins enough, zinc chloride begins to leak out of the battery. The old dry cell is not leak-proof and becomes very sticky as the paste leaks through the holes in the zinc case. The zinc casing in the dry cell gets thinner even when the cell is not being used, because the ammonium chloride inside the battery reacts with the zinc. An "inside-out" form with a carbon cup and zinc vanes on the interior, while more leak-resistant, has not been made since the 1960s.[1]

Progressive corrosion of zinc–carbon batteries

This picture shows the zinc container of fresh batteries at (a), and discharged batteries at (b) and (c). The battery shown at (c) had a polyethylene protection film (mostly removed in the photo) to keep the zinc oxide inside the casing.

Environmental impact

Thousands of tons of zinc–carbon batteries are discarded every year around the world and are often not recycled.

Disposal varies by jurisdiction. For example, in the U.S, the state of California considers all batteries as hazardous waste when discarded, and has banned the disposal of batteries with other domestic waste.[9] In Europe, battery disposal is controlled by the WEEE Directive and Battery Directive regulations, and as such zinc–carbon batteries must not be thrown out with domestic waste. In the EU, most stores that sell batteries are required by law to accept old batteries for recycling.

Disassembled zinc chloride cell (similar to zinc carbon cell). 1: entire cell, 2: steel casing, 3: zinc negative electrode, 4: carbon rod, 5: positive electrode (manganese dioxide mixed with carbon powder and electrolyte), 6: paper separator, 7: polyethylene leak proof isolation, 8: sealing rings, 9: negative terminal, 10: positive terminal (originally connected to carbon rod).

See also

- List of battery types
- List of battery sizes
- Comparison of battery types
- Photoflash battery

References

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External links

- Eveready: Carbon Zinc Application Notes (http://data.energizer.com/PDFs/carbonzinc_appman.pdf)
- Rayovac: Alkaline and Heavy Duty Application Notes (http://www.rayovac.com/Consumer-Services/Technical-OEM/~/media/Rayovac/Files/Product%20Guides/pg_battery.ashx)
- Power Stream Battery Chemistry FAQs (http://www.powerstream.com/BatteryFAQ.html)
- Cell Construction (http://www.doitpoms.ac.uk/tlplib/batteries/batteries_zn_c.php)
- Power dense zinc-manganese power unit as cheap as a car battery (http://newatlas.com/rechargeable-zinc-manganese-battery-pnnl/42930/?li_source=LI&li_medium=default-widget)