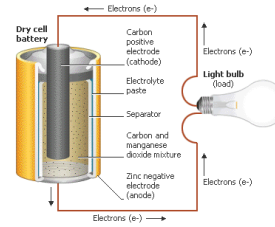
Lecture 9

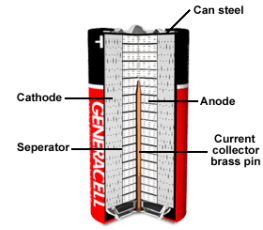
Batteries

1. Introduction



- Batteries are complex electrochemical devices, composed of distinct cells, that generate electrical energy from the chemical energy of their cell components
- A battery cell consists primarily of a metallic anode (negative electrode), a metallic oxide cathode (positive electrode) and an electrolyte material that facilitates the chemical reaction between the two electrodes.

1. Introduction



- Electric currents are generated as the anode corrodes in the electrolyte and initiates an ionic exchange reaction with the cathode
- Batteries are used in motor and marine vehicles, electronics, watches, cameras, calculators, hearing aids, cordless telephones, power tools and countless other portable household devices.

How do batteries work?

Video: http://www.youtube.com/watch?v=KkRwuM4S8BQ

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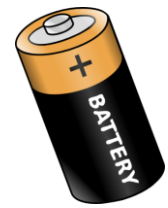
1. Introduction



- Batteries are classified and distinguished according to their chemical components.
- Batteries are referred to as wet or dry cells.
- In wet cell batteries, the electrolyte is a liquid.
- In dry cell batteries, the electrolyte is contained in a paste, gel or other solid matrix within the battery.
- Primary batteries contain cells in which the chemical reactions are irreversible, and they therefore cannot be recharged.

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1. Introduction

- In secondary batteries, the chemical reactions are reversible and external energy sources can be repeatedly applied to recharge the battery cells.
- Batteries are manufactured in a variety of sizes, shapes, and voltages.
- They are produced in rectangular, cylindrical, button, and coin shapes.
- In addition, many portable tools and electronic devices utilize rechargeable batteries contained in battery packs

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2. Types and Uses of Batteries

Battery type	Shapes	Uses
Wet cells Lead-acid	Rectangular	Cars, motorcycles, boats
Dry cells—primary Zinc-carbon Alkaline	Cylindrical, rectangular, button; AA, AAA, C, D, 9V	Flashlights, radios, tape recorders, toys
Mercuric oxide Silver oxide Zinc air Lithium	Button, cylindrical	Hearing aids, watches, calculators, pagers, camcorders, computers, cameras
Dry cells—secondary Nickel-cadmium Lead-acid	Cylindrical, button, or in battery packs	Rechargeable cordless products such as power tools, vacuum cleaners, shavers, phones

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2. Types and Uses of Batteries

- Batteries differ in their chemical composition, energy storage capacity, voltage output, and life span.
- These factors affect their overall performance, utility and cost.
- Because of their different intended uses, consumer batteries are usually distinguished as:
  - automotive batteries (wet cells)
  - household batteries (dry cells)

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Lead-acid storage batteries (wet cells)

- Lead-acid storage batteries are used in automobiles, motorcycles, boats and several industrial applications.
- They are primarily used to provide starting, lighting and ignition for automotive products.
- These are wet cell batteries consisting of lead electrodes in a liquid sulfuric acid electrolyte.
- The average battery weighs ~16 kg, one-half of which is composed of lead anode and lead dioxide cathode

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Lead-acid storage batteries (wet cells)

- In addition to lead, each battery contains;
  - ~ 4 L of sulfuric acid,
  - ~ 1.5 kg of polypropylene plastic casing,
  - ~ 1.5 kg of polyvinyl chloride rubber separators, and
  - ~ 1.5 kg of various chemical sulfates and oxides to which the lead is bound.
- The typical useful lifetime of lead-acid storage batteries is 3 to 4 years.

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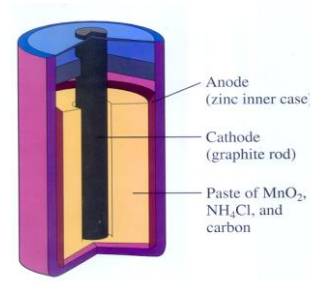
Household batteries (dry cells)

- Dry cell batteries contain electrodes composed of a variety of potentially hazardous metals including Cd, Hg, Ni, Ag, Pb, Li and Zn.



- In addition to electrodes and electrolytes, batteries also contain other materials that are added to control or contain the chemical reactions within the battery.

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Household batteries (dry cells)

- Hg is added to the Zn anode of primary cells (e.g. alkaline, Zn-carbon) to reduce corrosion and to inhibit the buildup of potentially explosive H_2.
- In addition, Hg helps to prevent the batteries from self-discharging and leaking.
- Other components of batteries include graphite, brass, plastic, paper, cardboard and steel.

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Household batteries (dry cells)

Primary chemical components of household batteries

Battery type	Cathode	Anode	Electrolyte
Alkaline	Manganese dioxide	Zinc	Potassium and/or sodium hydroxide
Zinc-carbon	Manganese dioxide	Zinc	Ammonium and/or zinc chloride
Mercuric oxide	Mercuric oxide	Zinc	Potassium and/or sodium hydroxide
Zinc-air	Oxygen from air	Zinc	Potassium hydroxide
Silver oxide	Silver oxide	Zinc	Potassium and/or sodium hydroxide
Lithium	Various metallic oxides	Lithium	Various organic and/or salt solutions
Nickel-cadmium (rechargeable)	Nickel oxide	Cadmium	Potassium and/or sodium hydroxide
Sealed lead-acid (rechargeable)	Lead oxide	Lead	Sulfuric acid

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Primary dry cell batteries

- Primary dry cell batteries are generally less expensive than secondary or rechargeable batteries.
- However, consumers should consider that rechargeable batteries are reusable whereas primary batteries must be replaced once they are discharged.
- The majority of batteries purchased are cylindrical and rectangular varieties.
- Button cells are used less.

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Primary dry cell batteries: Alkaline (Mn) batteries

- They are the most common household dry cell batteries and manufactured in many sizes and shapes.
- Their good performance and long shelf life make them appealing for a variety of consumer uses.
- Recent environmental concerns have resulted in dramatic reductions in their Hg content.
- Batteries that contained up to 1% Hg by weight in the mid-1980s are now being produced with mercury concentrations of 0.0001 to 0.025%.

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Primary dry cell batteries: Alkaline (Mn) batteries

- Because of design limitations, such reductions will be more difficult to achieve for button-size batteries than for cylindrical and rectangular batteries
- The major alkaline battery manufacturers have established implementation dates for no-Hg-added battery designs for non-button cells by 1993.
- In addition to mercury, alkaline batteries also contain metals such as lead, cadmium, arsenic, chromium, copper, indium, iron, nickel, tin, zinc, and manganese

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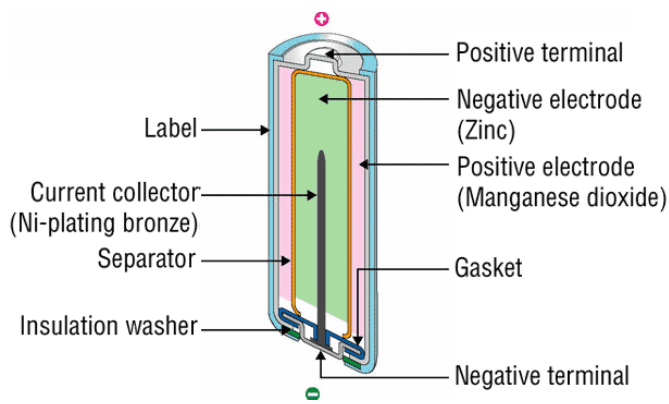
Primary dry cell batteries: Alkaline (Mn) batteries



http://www.baj.or.jp/e/knowledge/structure.html

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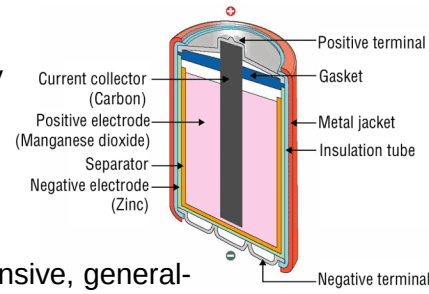
Primary dry cell batteries: Zn-carbon batteries



- The 2nd most commonly used household battery, however sales of them are declining.
- Manufactured as inexpensive, general-purpose batteries as well as heavy-duty varieties.
- Have a shorter shelf life than alkaline batteries, are less powerful, and have a tendency to leak in devices once they are discharged.

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Primary dry cell batteries: Zn-carbon batteries

- Because of their anode configuration, they require less mercury than alkaline batteries.
- Reduction and eventual elimination of added Hg to Zn-carbon batteries is anticipated in the near future.
- In addition to mercury, Zn-carbon batteries also contain metals such as lead, cadmium, arsenic, chromium, copper, iron, manganese, nickel, zinc, and tin.

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Primary dry cell batteries: Silver oxide batteries

- Manufactured in a variety of button sizes and provide a more constant voltage output than alkaline or Zn-carbon button cells.
- Interchangeable with mercuric oxide batteries and are increasingly being used to power hearing aids/watches.
- Generally more expensive than mercuric oxide cells.
- Contain about 1% Hg by battery weight.

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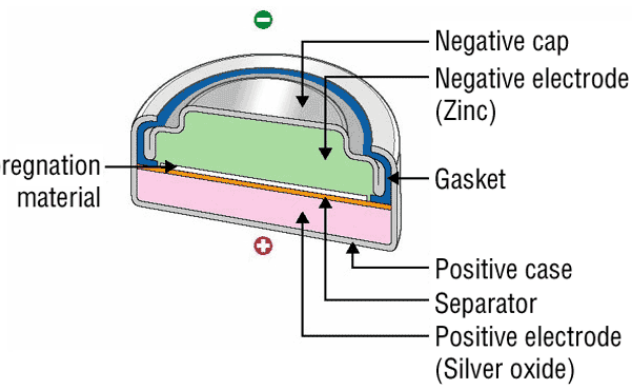
Primary dry cell batteries: Silver oxide batteries



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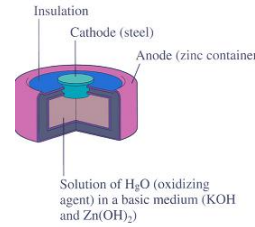
Primary dry cell batteries: Mercury oxide batteries

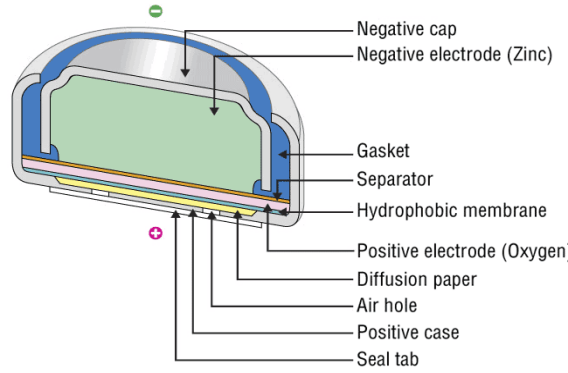


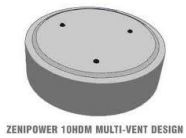
- Most HgO batteries are manufactured as button cells.
- Increasingly have come under scrutiny since more than one-third of their weight is mercury.
- Suitable alternatives have been developed (ZnO, Zn-air) that should reduce consumer dependence on HgO cells.
- Despite their decreasing use by household consumers, HgO batteries continue to be used in a variety of industrial, medical, military, and communications devices

Primary dry cell batteries: Zn-air batteries

- Become increasingly popular as household button cell.
- Primary uses are in hearing aids and pagers.
- Have a longer life than silver or mercuric oxide batteries.
- Their use is restricted since they require ambient air to provide their oxygen cathode.
- Cannot be used for tightly sealed applications (watches)
- Contain about 1 to 2% Hg by weight.

Primary dry cell batteries: Zn-air batteries



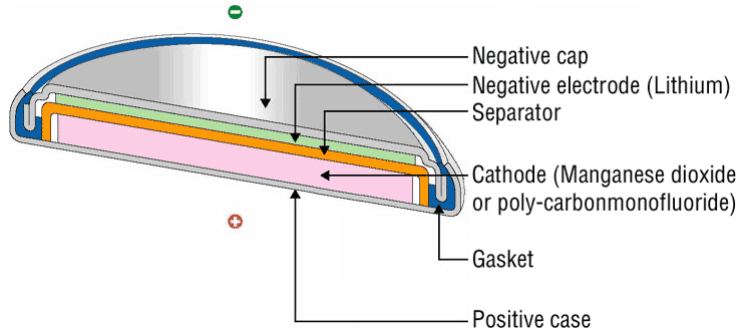


http://www.baj.or.jp/e/knowledge/structure.html

Primary dry cell batteries: Lithium batteries

- Manufactured as cylinders, buttons or coin shapes and may also be contained in battery packs.
- Despite their high cost, their excellent performance characteristics make them useful in a variety of consumer electronics and computer applications.
- Li is a highly reactive material when mixed with water.
- Safety precautions are recommended when collecting, storing or transporting unspent batteries for disposal.
- Their market share is expected to increase in the future

Primary dry cell batteries: Lithium batteries



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Secondary dry cell batteries

- These rechargeable batteries are preferable to primary cells since they can be used repeatedly.
- However, their lower performance characteristics may be restrictive for some consumer applications
- One rechargeable battery can substitute for 100 to 300 single-use batteries.

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Secondary dry cell batteries

- Many rechargeable batteries are sealed within consumer products such as cellular phones, PCs, other electronics.
- Easy access to rechargeable batteries in consumer products encourages their recycling or proper disposal.

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Secondary dry cell batteries: Ni-Cd batteries

- The most common rechargeable household batteries.
- Available in sizes comparable with alkaline and zinc-carbon batteries.
- However, they are currently not as powerful as primary cells and tend to discharge more rapidly.
- Typically have a Cd content ranging from 11 to 15% of the battery weight.

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Secondary dry cell batteries: Sealed lead-acid batteries

- In addition to automotive uses, sealed lead-acid batteries are used in a variety of consumer products such as toys, video recorders, portable electronics, tools, appliances, and electric start lawn mowers.
- These smaller, rechargeable batteries are dry cells since the sulfuric acid electrolyte is contained on a solid separator material or in a gel.

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3. Environmental Impacts

- The disposal of used automobile and household batteries into MSW must be assessed for its potential human and environmental health impacts.
- Used batteries in MSW;
  - Contribute to the total quantity of potentially HW that is disposed in MSW and
  - Contain many potentially toxic chemicals that can have adverse environmental and human health impacts.
- Potentially toxic heavy metals that may be present in batteries include Hg, Cd, Pb, Ag, Zn, Ni, Mn, Li, Cr, As.

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3. Environmental Impacts

Weight percentage of potentially toxic heavy metals in common household batteries

	Metal, %				
Battery type	Cadmium	Mercury	Nickel	Silver	Zinc
Alkaline	0.01	0.025–0.5			8–18
Zinc-carbon	0.03	0.01			12–20
Mercuric oxide		30–43			10–15
Silver oxide		1.0		30–35	30–35
Zinc air		2.0			35–40
Nickel-cadmium	11–15		15–25		

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3. Environmental Impacts

- Anually a significant amount of lead is used to manufacture lead-acid batteries.
- Most of this is used to manufacture automobile batteries.
- Lead-acid storage batteries comprise the largest percentage of the weight of batteries discarded.
- The effectiveness of lead-acid battery recycling programs significantly impact the weight of lead-acid batteries that are landfilled or incinerated.

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3. Environmental Impacts

- Household dry batteries are the most common sources of cadmium and mercury in MSW.
- Alkaline batteries accounted for the largest quantity of the total weight of Hg in MSW.
- As Ni-Cd batteries increase in popularity, the amount of Cd in the waste stream is expected to increase.
- Although the sales of household batteries increase, the amount of Hg in MSW is expected to decrease in future.
- This is due to further reductions in Hg content of dry cells as well as to the use of alternatives for HgO batteries.

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4. Collection of Used Batteries

- Battery collection programs are intended to separate batteries from MSW and keep them out of MSW landfills.
- Such programs are designed to recover certain types of batteries for reclamation & recycling of their components.
- Used batteries are collected through community-sponsored drop-off locations, residential curbside collection programs, HHW collection centers & retailers.
- A battery collection program should include ongoing public education to increase consumer participation and awareness of the types of batteries.

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Collection of automobile batteries

- The success of automobile lead-acid battery collection programs results from the implementation of centralized and convenient collection locations such as automotive parts stores and service centers.
- In addition, the collection of lead-acid batteries is supported by the secondary lead industry, which reclaims and markets the battery components.

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Video: http://www.youtube.com/watch?v=Qg-T8rn4iKo&feature=relmfu

Collection of household batteries

- Communities may choose:
  - not to collect any household batteries,
  - to collect only those batteries that can be reclaimed
  - to collect only the most toxic batteries, or
  - to collect all used household batteries.
- Consumers are encouraged to bring their spent household batteries to approved collection facilities for proper handling.
- Collected batteries should be stored in well-ventilated areas to avoid the buildup of heat as well as Hg and H_2.

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Collection of household batteries

- Facilities should also have adequate safety and fire-prevention equipment.
- Batteries should be stored in a dry environment and packed to minimize the potential hazards from short-circuits, leaking cells, and unspent lithium cells.

Curbside Battery Collection Container

Video-1 : http://www.youtube.com/watch?v=hPSICQztRm8
Video-1 : http://www.youtube.com/watch?v=14dW1chYAZc

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5. Recycling Used Batteries

- Used batteries cannot be recycled in the same sense that glass and platics are recycled into new products.
- The battery components that can be reclaimed and reused include metals (Pb, Hg, Ag, Ni, Cd, steel) and plastic (e.g., the battery case of automobile batteries).
- The reclaimed materials may then be recycled into new battery components or manufactured into other products.
- Programs for household batteries essentially focus primarily on battery collection and safe disposal rather than reclamation.

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Recycling of automobile batteries

- Historically, lead-acid battery recycling rates have reflected the market conditions for Pb.
- The recent goal is to maintain a high recycling rate despite market fluctuations in Pb prices or reductions in processing capacity.
- Lead-acid batteries are recycled to reclaim the Pb, sulfuric acid and polypropylene plastic housing.
- At the smelter, the batteries are crushed and then processed to recover the battery components.

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Video: http://www.youtube.com/watch?v=gGvmn6Aat5A&feature=related

Recycling of automobile batteries

- The sulfuric acid can be reclaimed and used in fertilizer or neutralized for disposal.
- The plastic battery case can be recycled into new cases or other recycled plastic products.
- All lead-containing components are loaded into furnaces in which the lead is melted and extracted.
- The furnace residue is further processed in blast furnaces to recover more of the lead.
- The slag that remains still contains Pb, must be tested prior to disposal to determine its HW characteristics.

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Recycling of household batteries

- Recycling of household batteries are not widespread.
- Household batteries are usually either shipped overseas for reclamation or disposed in domestic HW landfills.
- The mercury present in these batteries complicates the reclamation of other battery components.
- Expensive Hg recovery systems are required before the Zn, steel, brass, Mn and carbon can be recovered safely from alkaline and zinc-carbon batteries.

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Video: http://www.youtube.com/watch?v=nCA6McK-Pz8