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](http://www.youtube.com/watch?v=KkRwuM4S8BQ)

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.
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.

2. Types and Uses of Batteries

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

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.
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.

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.
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 H₂.
- 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.

Household batteries (dry cells)

Primary chemical components of household batteries

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

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%.
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.

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

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.
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.

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

- Negative cap
- Negative electrode (Lithium)
- Separator
- Cathode (Manganese dioxide or poly-carbonmonofluoride)
- Gasket
- Positive case

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

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.
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.

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.
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.

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.
3. Environmental Impacts

Weight percentage of potentially toxic heavy metals in common household batteries

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Cadmium</th>
<th>Mercury</th>
<th>Nickel</th>
<th>Silver</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline</td>
<td>0.01</td>
<td>0.025-0.5</td>
<td></td>
<td></td>
<td>8-18</td>
</tr>
<tr>
<td>Zinc-carbon</td>
<td>0.03</td>
<td>0.01</td>
<td></td>
<td></td>
<td>12-20</td>
</tr>
<tr>
<td>Mercuric oxide</td>
<td>30-43</td>
<td></td>
<td></td>
<td></td>
<td>10-15</td>
</tr>
<tr>
<td>Silver oxide</td>
<td>1.0</td>
<td></td>
<td>30-35</td>
<td>30-35</td>
<td></td>
</tr>
<tr>
<td>Zinc air</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td>35-40</td>
</tr>
<tr>
<td>Nickel-cadmium</td>
<td>11-15</td>
<td>15-25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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3. Environmental Impacts

- An annually 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.

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.
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.

Video: http://www.youtube.com/watch?v=Qg-T8m4iKo&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 H₂.
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.

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

5. Recycling Used Batteries

- Used batteries cannot be recycled in the same sense that glass and plastics 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.
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.

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

Video: [http://www.youtube.com/watch?v=nCA6McK-Pz8](http://www.youtube.com/watch?v=nCA6McK-Pz8)