Introduction Batteries

Details in Chapter 4
Batteries introduction

• **Definition**: devices that transform chemical energy into electricity

• Every battery has two terminals: the positive **cathode** (+) and the negative **anode** (-)

• **Functioning**
  • Device switched on -> chemical reaction started - electrons produced - electrons travel from (-) to (+) **electrical work is produced**
Batteries - introduction

• Batteries consist of electrochemical cells that are electrically connected

• An electrochemical cell comprises:

  • 1. a negative electrode to which anions (negatively charged ions) migrate, i.e., the anode – donates electrons to the external circuit as the cell discharges

  • 2. a positive electrode to which cations (positively charged ions) migrate, i.e., the cathode

  • 3. electrolyte solution containing dissociated salts, which enable ion transfer between the two electrodes, providing a mechanism for charge to flow between positive and negative electrodes

  • 4. a separator which electrically isolates the positive and negative electrodes.
Primary and Secondary Batteries

• Primary batteries are disposable because their electrochemical reaction cannot be reversed.

• Secondary batteries are rechargeable, because their electrochemical reaction can be reversed by applying a certain voltage to the battery in the opposite direction of the discharge.
Electrochemical Cell
A simple battery
Battery for a vehicle
Batteries of daily life
Standard Modern Batteries

• Zinc-Carbon: used in all inexpensive AA, C and D drycell batteries. The electrodes are zinc and carbon, with an acidic paste between them that serves as the electrolyte. (disposable)
Standard Modern Batteries

• Alkaline: used in common Duracell and Energizer batteries, the electrodes are zinc and manganese-oxide, with an alkaline electrolyte. (disposable)
Standard Modern Batteries

• Lead-Acid: used in cars, the electrodes are lead and lead oxide, with an acidic electrolyte. (rechargeable)
Standard Modern Batteries

- Nickel-cadmium: (NiCd) rechargeable, “memory effect”
Standard Modern Batteries

• Nickel-metal hydride: (NiMH) rechargeable, “memory effect” (less susceptible than NiCd)
Nickel Metal Hydride Batteries (NiMH)

Positive electrode: NiOOH – nickel oxyhydroxide
Negative electrode: M a metal alloy able to absorb hydrogen
Electrolyte: Aqueous solution of 30 % potassium hydroxide (KOH) with high ionic conductivity

Discharging process:
Negative electrode: $\text{MH} + \text{OH}^- \rightarrow \text{M} + \text{H}_2\text{O} + \text{e}^-$
Positive electrode: $\text{NiOOH} + \text{H}_2\text{O} + \text{e}^- \rightarrow \text{Ni(OH)}_2 + \text{OH}^-$
Net reaction: $\text{NiOOH} + \text{MH} \rightarrow \text{Ni(OH)}_2 + \text{M}$
Standard Modern Batteries

• Lithium-Ion: (Li-Ion) rechargeable, *no* “memory effect”, high energy density, power rate, cycle life, costly
## Comparison of various cell chemistries

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Volt</th>
<th>Wh/kg (pack)</th>
<th>W/kg</th>
<th>Cycles</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead-acid</td>
<td>2</td>
<td>40(30)</td>
<td>180</td>
<td>600</td>
<td>70-92</td>
</tr>
<tr>
<td>Nickel-Cadmium (Ni-Cd)</td>
<td>1.2</td>
<td>50(47)</td>
<td>120</td>
<td>1500</td>
<td>70-90</td>
</tr>
<tr>
<td>Nickel-Metal Hydride (Ni-MH)</td>
<td>1.2</td>
<td>70(55)</td>
<td>200</td>
<td>1000</td>
<td>66</td>
</tr>
<tr>
<td>Lithium-Ion (Li-ion)</td>
<td>3.6</td>
<td>130(90)</td>
<td>430</td>
<td>1200</td>
<td>90</td>
</tr>
</tbody>
</table>
Number of Cells, Voltage and Battery Pack

• Battery means a system of one or more cells
• By connecting a number of cells in series, a battery pack is formed
• By combining cells in series, the voltage of the battery pack can be increased
Battery Capacity, Watt hours, Energy Density,

• The battery capacity $Q$ is the product of current and time, i.e., $Q = I \cdot t$ and unit is Ah (or mAh)

• Watt hours stored in a battery pack is approximated as the product of the Battery voltage and the rated Ampere hours, i.e., Watt hours = Battery Voltage•Ah

• Energy density is define as the energy in Watt hours per unit mass of the battery.
Comparison between various batteries
Some Issues

• **Energy Density:** Total amount of energy that can be stored per unit mass or volume. How long will your laptop run before it must be recharged?

• **Power Density:** Maximum rate of energy discharge per unit mass or volume. Low power: laptop, i-pod. High power: power tools.

• **Safety:** At high temperatures, certain battery components will breakdown and can undergo exothermic reactions.

• **Life:** Stability of energy density and power density with repeated cycling is needed for the long life required in many applications.

• **Cost:** Must compete with other energy storage technologies.
Illustration of parallel and series coupling of batteries

- **Parallel**
  - 200 Ah, 12 V
  - =2,4 kWh
  - 200 Ah, 12 V

- **Series**
  - 200 Ah, 12 V
  - =400 Ah, 12 V
  - = 4,8 kWh
  - 200 Ah, 12 V

=200 Ah, 24 V = 4,8 kWh
Depth of Discharge, DoD

• Sometimes maximum discharge stated as 50 %
• Might be specified as 500 cycles@DoD50, which means that the battery will withstand 500 charging/discharging cycles.
On Battery Management System

Figure 6.1 An example of work procedure of the BMS control unit.
State functions (SOF)

- SOC = state of charge, SOH = state of health,

\[
SOC = \frac{\text{Available capacity } Q(t)}{\text{Nominal capacity } Q_n}
\]

SOH = remaining capacity compared to capacity at beginning of battery life (BOL)

SOF power capability

Depth of Discharge, DoD = 100 - SOC (%) 

EOL = end of battery life

BMS = battery management system, BTMS = battery thermal management system
Lithium Batteries

Lithium metal was used but its instability rendered it unsafe.

The Lithium-Ion battery has a slightly lower energy density than Lithium metal, but is much safer. Introduced by Sony in 1991.
Chemical Intercalation

• Intercalation is the reversible inclusion of a molecule between two other molecules. Ex: graphite intercalation compounds.
• Graphite intercalation compounds are complex materials where an atom, ion, or molecule is inserted (intercalated) between the graphite layers. In this type of compound the graphite layers remain largely intact and the guest species are located in between
Lithium-Ion Battery

• A Li-ion battery is an electrochemical device which converts stored chemical energy directly into electricity.

• During charging an external voltage source pulls electrons from the cathode through an external circuit to the anode and causes Li-ions to move from the cathode to the anode by transport through an liquid electrolyte.

• During discharge the processes are reversed. Li-ions move from the anode to the cathode through the electrolyte while electrons flow through the external circuit from the anode to the cathode and produce power.

• To a large extent, the cathode material limits the performance of current Li-ion batteries
Principles of Lithium-ion battery
Materials negative electrodes

• Metallic lithium
• Carbon-based insertion materials (graphite)
• Alloys
• Oxides
Materials positive electrodes

• With (most common) or without Lithium
Electrolytes

• Liquid electrolytes; solvents, salts, polymer-based, ionic liquids
Advantages of Li-ion batteries

- **POWER** – High energy density means greater power in a smaller package.

- 60% greater than NiMH

- 220% greater than NiCd

- **HIGHER VOLTAGE** – a strong current allows it to power complex mechanical devices.

- **LONG SELF-LIFE** – only 5% discharge loss per month.

- 10% for NiMH, 20% for NiCd
Electrode Materials

• None of the existing electrode materials alone can deliver all the required performance characteristics including high capacity, higher operating voltage, long cycle life and safety.

• RESEARCH AND DEVELOPMENT NEEDED
Electrolyte Challenges

• *Electrolyte Challenges:*
  • Liquid electrolyte
  • Problems: leakage, sealing, non-flexibility of the cells, side reactions with charged electrodes;

Risk for Explosions
Next Generation of Batteries

1) Lithium - Sulphur
Li at Anode; Carbon, Sulphur at Cathode
high energy density

2) Magnesium - Metal oxide/Organic material
Anode Mg; Metal oxide or Organic material at Cathode
High energy density
Mg cheap
Next Generation of Batteries

3) Lithium metal - Metal oxide, Metal Phosphate
   Li at Anode; Metal oxide, Metal Phosphate Cathode

4) Sodium - Metal oxide
   Sodium and Carbon at Anode; Metal at Cathode
   Sodium environmentally friendly
Lithium air battery

A lithium-air battery (Li-air) is a metal–air electrochemical cell or battery chemistry that uses oxidation of lithium at the anode and reduction of oxygen at the cathode to induce a current flow.

lithium-air battery has the potential of 5–15 times the specific energy of a lithium-ion battery as of 2016.
Lithium-air battery

High energy density.
On the cathode side Li-ions reacts with oxygen at the porous electrode surface. Lithium-per-oxide is formed which enables a rechargeable battery. The electrolyte involves Li salt dissolved in an organic solvent. MnO2 is used as a catalyst in the cathode to promote the reactions.
Flow battery

A flow battery, or redox flow battery, is a type of rechargeable battery where rechargeability is provided by two chemical components dissolved in liquids contained within the system and separated by a membrane. Ion exchange (providing flow of electric current) occurs through the membrane while both liquids circulate in their own respective space. Cell voltage is chemically determined by the Nernst equation and ranges, in practical applications, from 1.0 to 2.2 volts.