How to power your smartphone for a week!
What is a battery?

• A device that stores chemical energy in its active materials and converts it, on demand, into electrical energy by means of an *electrochemical reaction*
  
  – *Electrochemical reaction* is a chemical reaction involving the transfer of electrons

• Batteries are made up of one or more basic electrochemical units called *cells*.
  
  – *Cells* are usually connected in series to increase the voltage.
Types of batteries

• **Primary batteries** are used once and thrown away, like the alkaline batteries used in portable CD players
  – Electrochemical reactions are not reversible and active materials cannot be restored to their original state.

• **Secondary (or rechargeable) batteries** can be used many times, like the battery in cell phones and laptop computers
  – The electrochemical reactions are reversible, and the active materials can be restored to their original chemical composition.
Widely used rechargeable batteries

- **Lead acid (30-40 Wh/kg, 70-92% eff., 2V)**
  - Over 100 years old, and still the most widely used rechargeable battery in the world.

- **Nickel metal hydride (30-80 Wh/kg, 66% eff., 1.2 V)**
  - A high power battery chemistry similar to nickel cadmium, introduced in the 1980s. It is environmentally friendly, contains no toxic cadmium, and is replacing NiCd in many applications.

- **Lithium ion (160 Wh/kg, 99.9% eff., 3.6-3.7V)**
  - The newest and fastest growing rechargeable battery technology.
  - Theoretical capacity: 150-275mAh/g

**Main concerns:** large volumes, liquid technology, leakage, and toxicity
Real batteries

Grid: metal framework
Plate: metal & chemically active material

Electrolyte
Sponge Lead
Envelope Separator - Every Negative Plate

Nickel-cadmium cell
vent ball
cap
cover
seal
core
can
positive tab
separators
pressed powdered negative electrode

“jelly roll”
Insulating washer
positive electrode

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Research batteries at ORNL
Actual technology and materials

Specific Energy, Wh/kg

Specific Power, W/kg

Where we are today

Where we need to go

Li-Air
Li-S
New chemistries

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# Cell potential

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Oxidation reaction</th>
<th>Standard potential (volts)</th>
<th>Nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>Li → Li⁺ + e⁻</td>
<td>+3.040</td>
<td>reducing agents</td>
</tr>
<tr>
<td>K</td>
<td>K → K⁺ + e⁻</td>
<td>+2.924</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>Ca → Ca²⁺ + 2e⁻</td>
<td>+2.870</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>Na → Na⁺ + e⁻</td>
<td>+2.710</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>Al → Al³⁺ + 3e⁻</td>
<td>+1.660</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>Zn → Zn²⁺ + 2e⁻</td>
<td>+0.762</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>Fe → Fe²⁺ + 2e⁻</td>
<td>+0.441</td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>Cd → Cd²⁺ + 2e⁻</td>
<td>+0.403</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>Ni → Ni²⁺ + 2e⁻</td>
<td>+0.236</td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>Sn → Sn²⁺ + 2e⁻</td>
<td>+0.140</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>Pt → Pt²⁺ + 2e⁻</td>
<td>+0.126</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>Cu → Cu²⁺ + 2e⁻</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>Ag → Ag⁺ + e⁻</td>
<td>-0.337</td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>Hg → Hg²⁺ + 2e⁻</td>
<td>-0.799</td>
<td></td>
</tr>
<tr>
<td>Cl₂</td>
<td>Cl₂ → Cl⁻ + e⁻</td>
<td>-0.920</td>
<td>oxidising agents</td>
</tr>
</tbody>
</table>

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Cell capacity

\[ F = \frac{It}{n} = \frac{C}{n} = N_A e \]

\[ C = \frac{zF}{M} \]

\[ \text{LiC}_6 \leftrightarrow \text{Li}^+ + 1e^- + C_6 \]

\[ z = 1; \quad M(C) = 6 \cdot 12.01 \frac{\text{g}}{\text{mol}} \]

\[ \Rightarrow C = 0.372 \frac{\text{Ah}}{\text{g}} \]

\[ \text{Li}_{22}\text{Si}_5 \leftrightarrow 22\text{Li}^+ + 22e^- + \text{Si}_5 \]

\[ z = 22; \quad M(Si) = 5 \cdot 28.09 \frac{\text{g}}{\text{mol}} \]

\[ \Rightarrow C = 4.200 \frac{\text{Ah}}{\text{g}} \]
Cell energy

- Capacity x voltage
- Cut off voltage is controlling available energy but also limiting access for safe operation

![Graph showing voltage over time with overcharge and overdischarge regions, and the importance of detecting the "knee" to prevent deep discharge.](image)
Lithium ion battery principle

Discharge reaction: $\text{Li}^+ + e^- + \text{MeO}_2 \rightarrow \text{LiMeO}_2$  
$\text{LiC}_6 \rightarrow \text{Li}^+ + e^- + \text{C}_6$
Development targets and accomplishments

Hybrid electric vehicles (HEV)

Plug-in Hybrid electric vehicles (PHEV)

Fruit battery – Natural galvanic element

[Diagram of a lemon with electrodes and ions labeled Zn, Cu, and Zn²⁺, Cu²⁺]
Have fun and stay safe!