National Transportation Safety Board
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Introduction to Batteries and Li-Ion Cells

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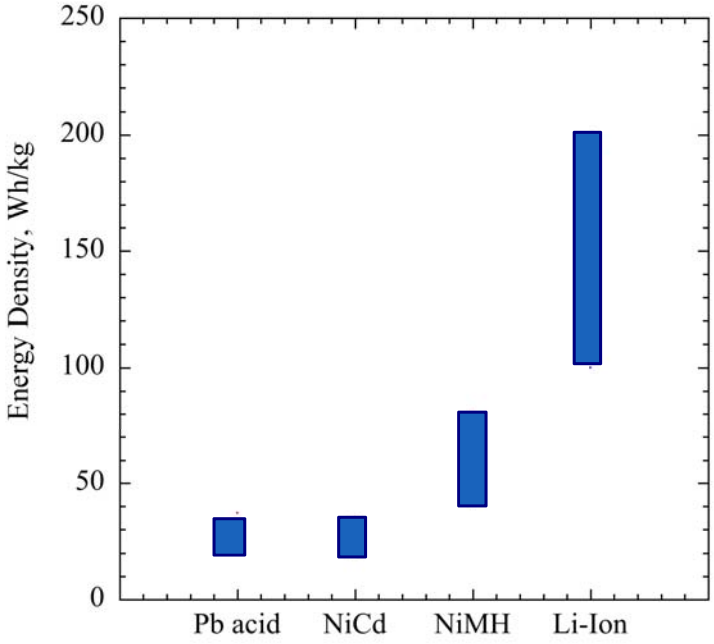
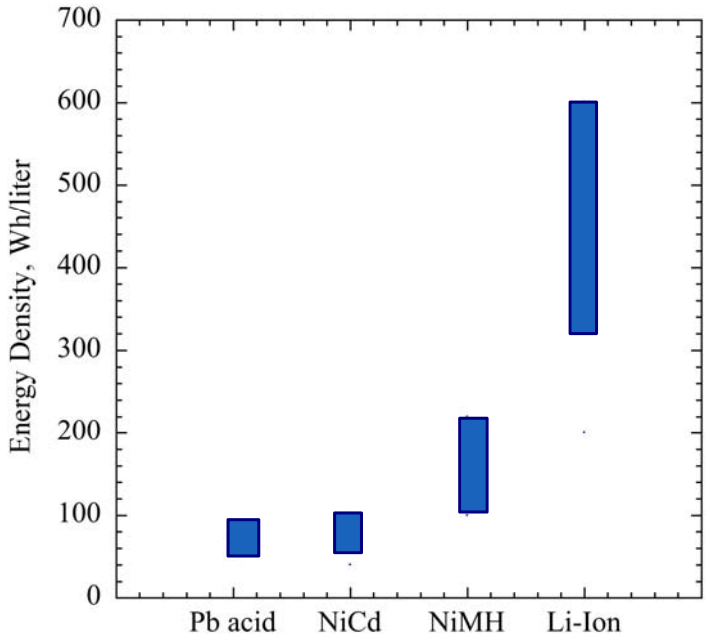
Why the Interest in Lithium Batteries?

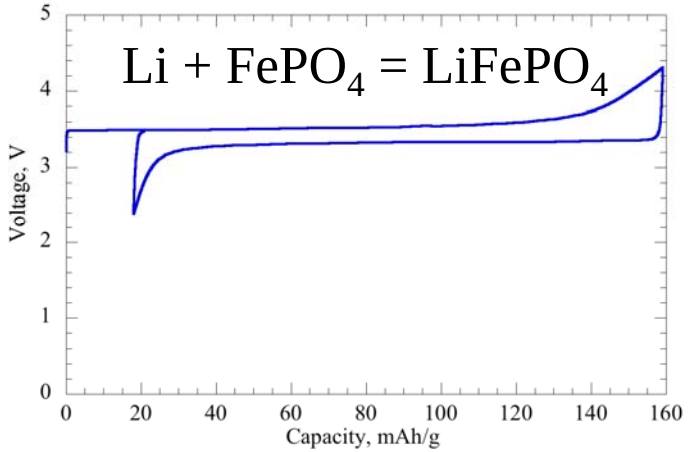
- **Energy storage for lithium batteries much higher than for other batteries**
  - **Li batteries have lower weight**
  - **Li cells have higher voltage, 3-4 volts, vs 1-2 volts for others**





What are Batteries?

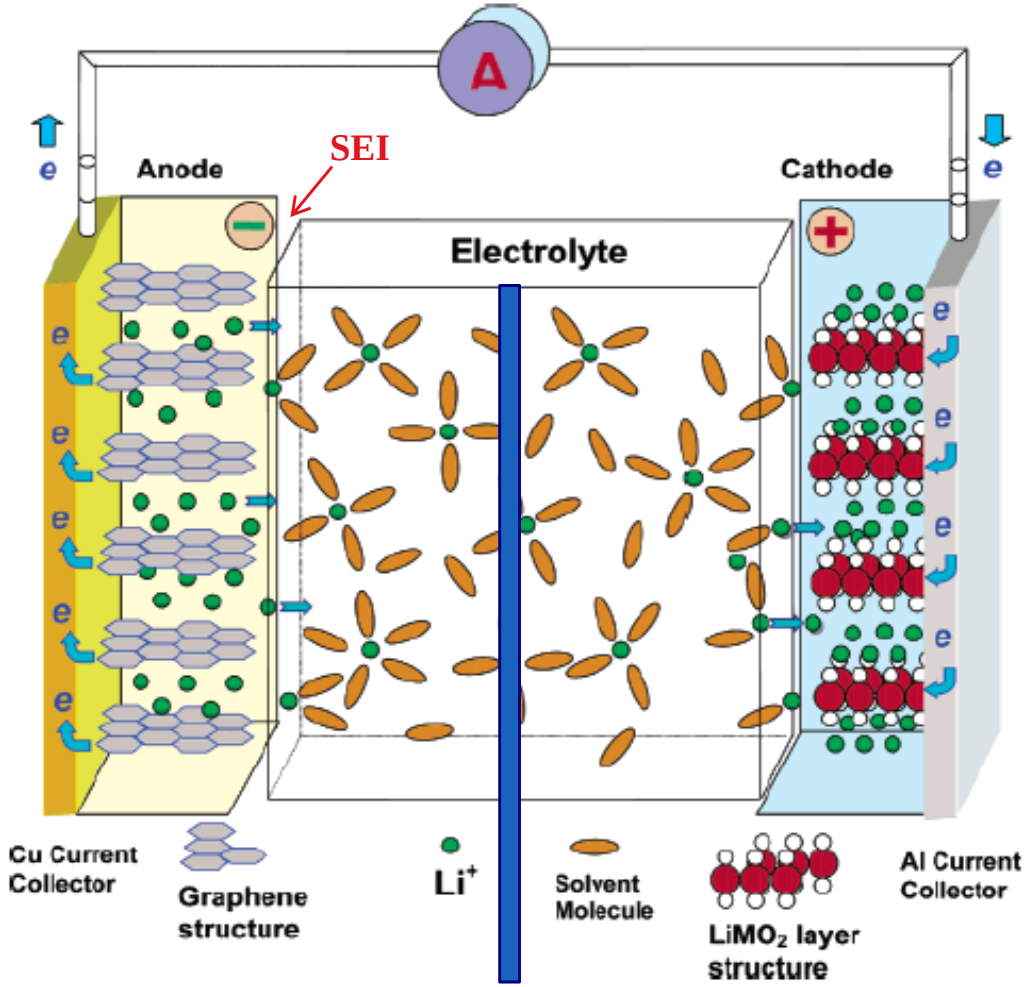
- **Batteries are devices that convert chemical energy into electrical energy**
  - **$\Delta G = nEF$***
  - **As an example for Li + $FePO_4$ giving $LiFePO_4$**
    - **At one electrode Li is ionized: $Li^+ + e^-$**
    - **At other electrode $Li^+ + e^-$ combine in the $FePO_4$ giving $LiFePO_4$**
    - **Electron goes through external circuit providing electricity**
    - **Capacity = 26.8/158 = 170 Ah/kg (n = 1, molar mass = 157.7)**
    - **Energy density = 3.45 * 170 = 586 Wh/kg**



* ΔG – free energy of reaction; n = number of electrons, E is the cell voltage, and F is Faraday's constant (26.8 Ah/mole Li)

Lithium-Ion Battery Cell: Components and Function

Structure Retention Electrodes



Separator

Polymeric

The Anode – Carbon Intercalation
Pure Lithium not safe

➢ **The Anode**

- **Pure lithium metal not used in any rechargeable batteries in the US**

+Electrodeposition

- Dendrites “always” form

- Lithium held in carbon

- But must not charge too fast

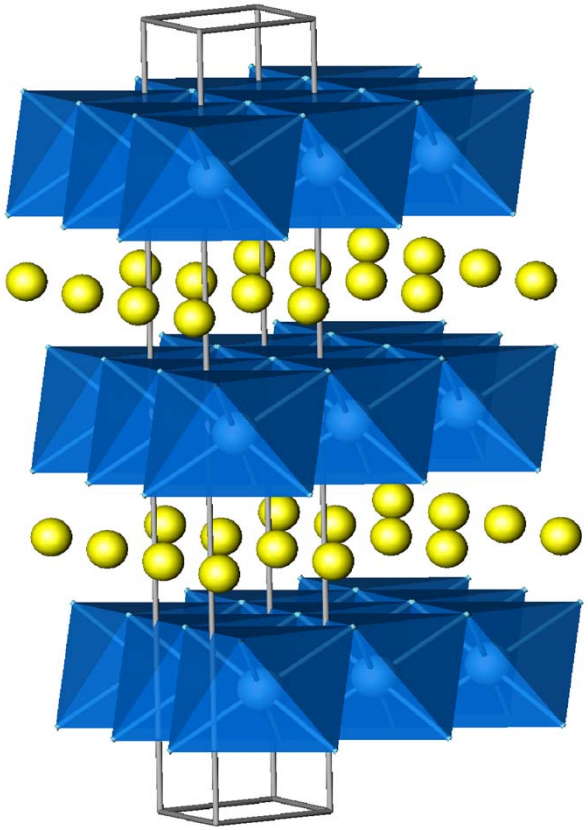
Avestor - AT&T

The Electrolyte – Non-aqueous

- **The Electrolyte**
  - Lithium not stable with water
    - Li salt in non-aqueous solvents used
      - Normally organic carbonate solvents
      - Normally $LiPF_6$ salt
    - Major issue
      - Unlike water, no built-in overcharge protection
        - Each cell must be electronically protected, if in series connection
- **SEI: The Electrolyte – Anode Interface**
  - A solid protective layer is formed on the surface of the anode during the first few cycles – this is done during the manufacturing process
    - It protects the the Li in the anode from reacting with the electrolyte
  - This is known as the Solid Electrolyte Interface

The Cathode – Intercalation Oxides/Phosphates

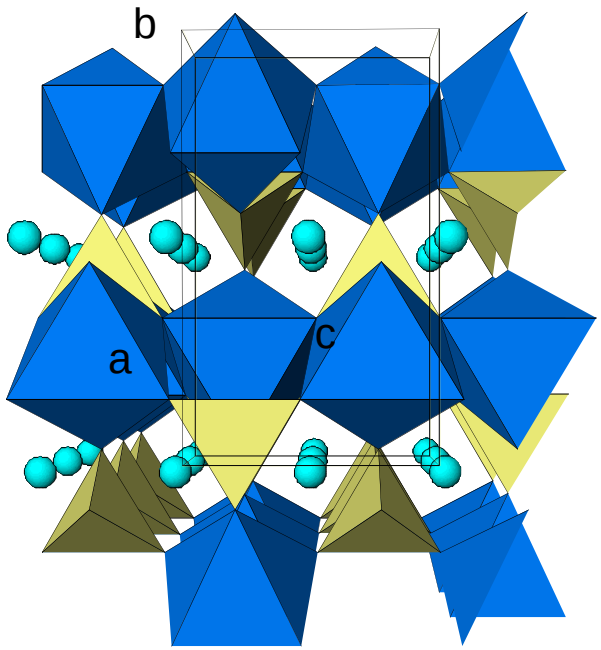
$LiTiS_2$ – $LiCoO_2$ – $Li(MnNiCo)O_2$



MO_6 octahedra

LiO_6 octahedra

$LiFePO_4$



- The particular cathode is chosen to meet the desired goals of energy, power, cost and safety
- Cathode electrode is a complex composite of the active material mixed with an electronic conductor and a binder

History of Li-Ion Batteries

First Generation (1973-):

Layered Sulfides

TiS_2 - LiAl – Exxon

EV Show Chicago, 1976

Still operating 2013

First Commercial Success (1991-):

Layered Oxides

$LiCoO_2$ - **LiC_6** – SONY

Tesla Motors

Today - 2013:

$Li(NiMnCoAl)O_2$

Spinel $LiMn_2O_4$

Olivine $LiFePO_4$

BAE Systems, Binghamton
11 kWh Li-ion
>2000 HEV buses in US
> 25 M miles

AES, Binghamton
8-20 MW Li-ion

Form Factors of Battery Cells (cell geometry)

Flat Plate (Prismatic/Pouch):

Flat plates

Bipolar (not in Li cells)

Coin or button cells:

Not used for transportation power

Spiral wound cells:

Dominant for Li-ion

18650 is one example

18 mm diam x 65 mm long

Batteries made of stacking cells:

In series for higher voltage

In parallel for higher current

Usually in combination of both

Performance Metrics for Battery Applications in Transportation

➢ **The metrics are very dependent on the specific application**

- HEV, mild PHEV and stop/start – lifetime/cost most important
  - High rate needed for regenerative breaking, restart
  - NiMH, Ultra Pb acid, Li-ion (+ possibly supercaps)
  - 11 kWh Li-ion buses (BAE Systems) have gone more than 25 M miles
- PHEV and EV require larger batteries with severe volume (and weight) constraints, particularly in consumer vehicles
  - Only Li can meet needs amongst present batteries
    - Chemistry chosen to meet specific needs
  - Small EV car needs 1 kWh per 4 miles
    - For 200 miles, >170 liters of batteries
  - EV Bus needs 1.4 - 2.5 kWh per mile
    - For 100 miles, > 500 - 800 liters