Hazards, Safety and Design Considerations for Commercial Lithium-ion Cells and Batteries

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Introduction

- Highest Energy Density of Rechargeable Battery Chemistries
- No metallic lithium
- Leading edge technology
- Contains flammable electrolyte
- Charge cut-off voltage is critical (overcharge can result in fire)
- Open circuit voltage higher than metallic lithium anode types with similar organic electrolytes
- Intercalation is a process that places small ions in crystal lattice. Small ions (such as lithium, sodium, and the other alkali metals) can fit in the interstitial spaces in a graphite lattice. These metallic ions can go farther and force the graphitic planes apart to fit two, three, or more layers of metallic ions between the carbon sheets.
- The graphite is conductive.
- Very high energy density compared to NiMH or NiCd
- Corrosion of aluminum occurs very quickly in the presence of air and electrolyte due to the formation of HF from LiPF6 and HF is highly corrosive.
- For DoT, lithium equivalents should be calculated: 0.3 g per Ah.
Typical Li-ion Cylindrical Cell Construction

[Diagram of a Li-ion cylindrical cell with labeled parts: Positive cap, Positive tab, Safety, Separator, Gasket, Insulator, Can, Center pin, Positive electrode, Negative electrode, Negative, Judith Jeevarajan/NASA-JSC]
Schematic Depicting Li-ion Charge/Discharge Process

Intercalation
Deintercalation
Li-ion Cell Reactions

Anode: Carbon compound (graphite)

Cathode: Lithium metal oxide such as LiCoO$_2$, LiNi$_{0.3}$Co$_{0.7}$O$_2$, LiNiO$_2$, LiV$_2$O$_5$, LiMn$_2$O$_4$, LiNiO$_{0.2}$Co$_{0.8}$O$_2$

Electrolyte: LiPF$_6$ (has a problem with aluminum corrosion), combination of carbonates (Co is very expensive)

The half reactions are:

- Cathode: $\text{LiMO}_2 \rightarrow \text{Li}_{1-x}\text{MO}_2 + x\text{Li}^+ + xe^-$
- Anode: $\text{C} + x\text{Li}^+ + xe^- \rightarrow \text{Li}_x\text{C}$

The overall reaction is: $\text{LiMO}_2 + \text{C} \Leftrightarrow \text{Li}_x\text{C} + \text{Li}_{1-x}\text{MO}_2$

Where LiMO$_2$ represents the lithiated metal oxide intercalation compound.
Typical Charge and Discharge for a Cylindrical 18650 Li-ion Cell

Charge: C/5
Discharge: 2.6 W
Hazards Associated with Commercial Li-ion Cells

- Overcharge
- Overdischarge into reversal
- External short Circuit
- Internal Short Circuit
- OverTemperature
Controls in Commercial Li-ion Cells and Batteries

Cell Level:
• PTC (Positive Temp. Coefficient) – External Short Protection
• CID (Current Interrupt Device) – Overcharge/overvoltage Protection
• Shut-down Separator

Battery Level:
“Smart” Circuit Board:
1. Cell Balancing
2. Individual cell/bank voltage monitoring
3. Current control
4. Hard-blow and thermal fuses
5. Overvoltage and Undervoltage cutoff using MOSFET switches
6. Thermal sensors
Overcharge of Commercial Li-ion Cells

- 2.4 A Charge
  CID trip in 42 min

- 0.6 A Charge
  No CID trip
Overcharge Tests on Li-ion Cells

4.8 A Charge

CID Trip in 18 min.

Internal Resistance Comparison
Limitations of Overcharge Protection ??

- Overcharge Protection in some COTS Cylindrical Cells is provided by the Current Interrupt Device.
- Works for single cells and a group of four cells but does not hold for higher voltage cell strings.
Overcharge Test on a 14-Cell String Showing Cell Temperatures for the Cylindrical Li-ion Cells

![Graph showing cell temperatures over time for 14 cylindrical Li-ion cells.](image)
Overdischarge into Reversal for a Li-ion Cell

![Graph showing voltage and temperature over time during a 1.2 A discharge.]
Simulated Internal Short or Crush Test on Moli Li-ion Cells

Cells 125 & 126 - Violent Vent with Fire

584°C Peak measured Temperatures
566°C

Judith Jeevarajan/NASA-JSC
Simulated Internal Short or Crush on Sanyo Lithium-ion Cells
External Short Circuit on a Li-ion Cell

![Graph showing Voltage, Current, and Temperature over time. The graph indicates an increase in Voltage and Temperature with time. The Y-axis represents Voltage and Current, while the X-axis represents Time (seconds). The graph also shows a PTC mechanism.]

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Battery Characteristics Under an External Short Test on a 14-Cell String of Sony Li-ion Cells
Cell Voltages During 14-Cell String Short Circuit Test on Cylindrical Li-ion Cells

![Graph showing cell voltages during a short circuit test. The graph plots voltage (V) against time (seconds) for 14 cells labeled Cell 1 to Cell 23. The graph shows the voltage drop and recovery over time for each cell.]
COTS Cell Uncertainties

- Quality Control may not be stringent enough.
- Always had issues with cells made under less stringent quality control methods.
- Contamination may cause internal shorts that can be hazardous after launch vibration.
- Can cause cell voltage divergence and hence overcharge or overdischarge if cell balancing is not available.
- At battery level, lack of quality control can again cause issues of shorting, high temperatures and resulting flame and fire.
Summary and Conclusions

- Due to lack of control over manufacturing line, need to have adequate heritage and data on cells and batteries used for flight.
- Need to perform engineering, qualification and flight acceptance testing.
- Need to perform Lot sample testing for each new lot.
- Need to understand cell and protective device limitations
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