Battery Pack Safety

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Scope

- The issues and battery packs discussed in this presentation will focus primarily on Lithium Ion technology.
- The battery packs associated with this presentation are considered to be LESS than 80Wh in capacity.

Outline

- Cell Chemistries
- Cell level Safety
- Pack Safety (Protection Circuits)
- Charging
- Approvals

Chemistries

- The most common battery technologies in Laptop Computers and Portable Data Terminals;
  - NiMH
  - Lithium-ion
  - Lithium Polymer (Just Starting)

- The main issues with all these technologies is their safety in severe over-charge situations. Problem with heat build up and thermal runaway conditions.

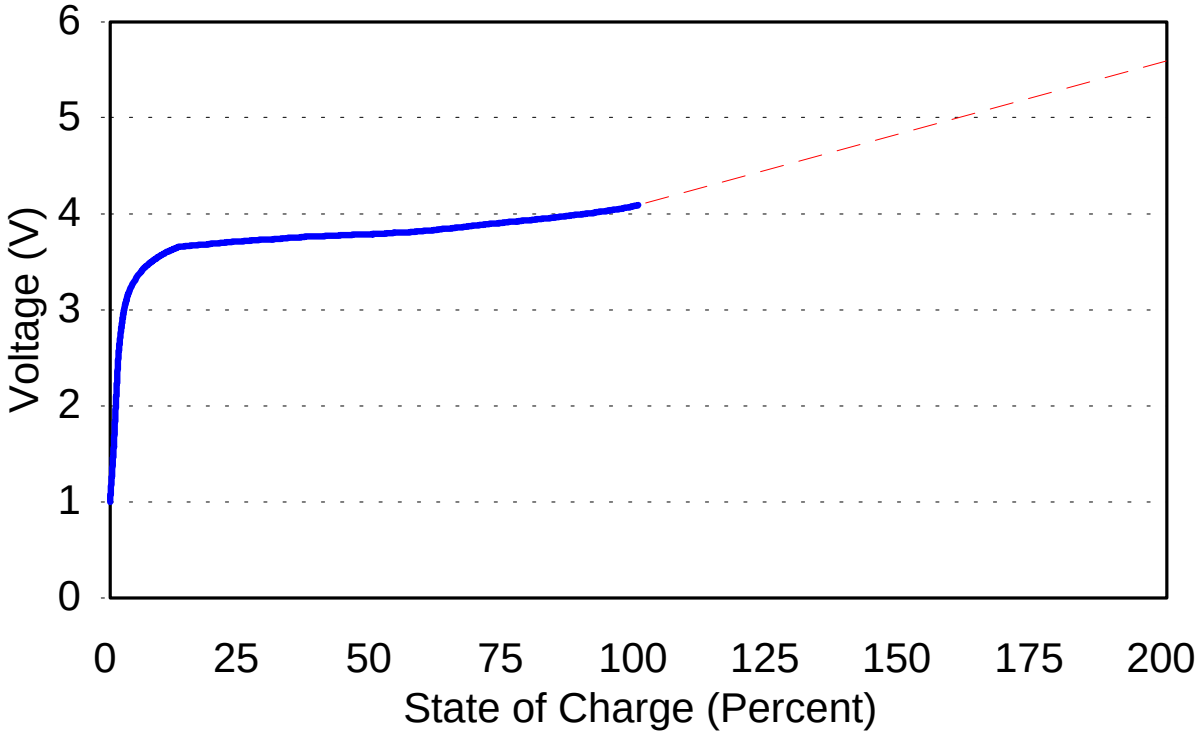
Protection for Lithium-ion Batteries

- There are usually 3 levels of protection against overcharge built into devices using Lithium-ion batteries;
  - Internal devices inside individual cells in a battery pack
  - A “protection” circuit built into the battery pack.
  - A proper charger
- Redundancy is very important to ensure the cells never reach an unsafe voltage.

What Happens on Overcharge

- Cobalt Li-ion cells are designed to operate safely within their normal operating voltage range, but become increasingly unstable if charged to higher voltages.
- Overcharging $LiCoO_2$ cells above their designed charge voltage will cause;
  - Lithium metal plating on Anode.
    - →Lithium metal is a powerful reducing agent. This is the reason Li-ion was developed.
  - The cathode material becomes unstable, becoming a strong oxidizing agent. (wants to release oxygen).
  - **Heating**
- **The lithium plating and destabilization of the cathode material make the cell more sensitive to thermal runaway. Consider also the cell contains a flammable electrolyte.**

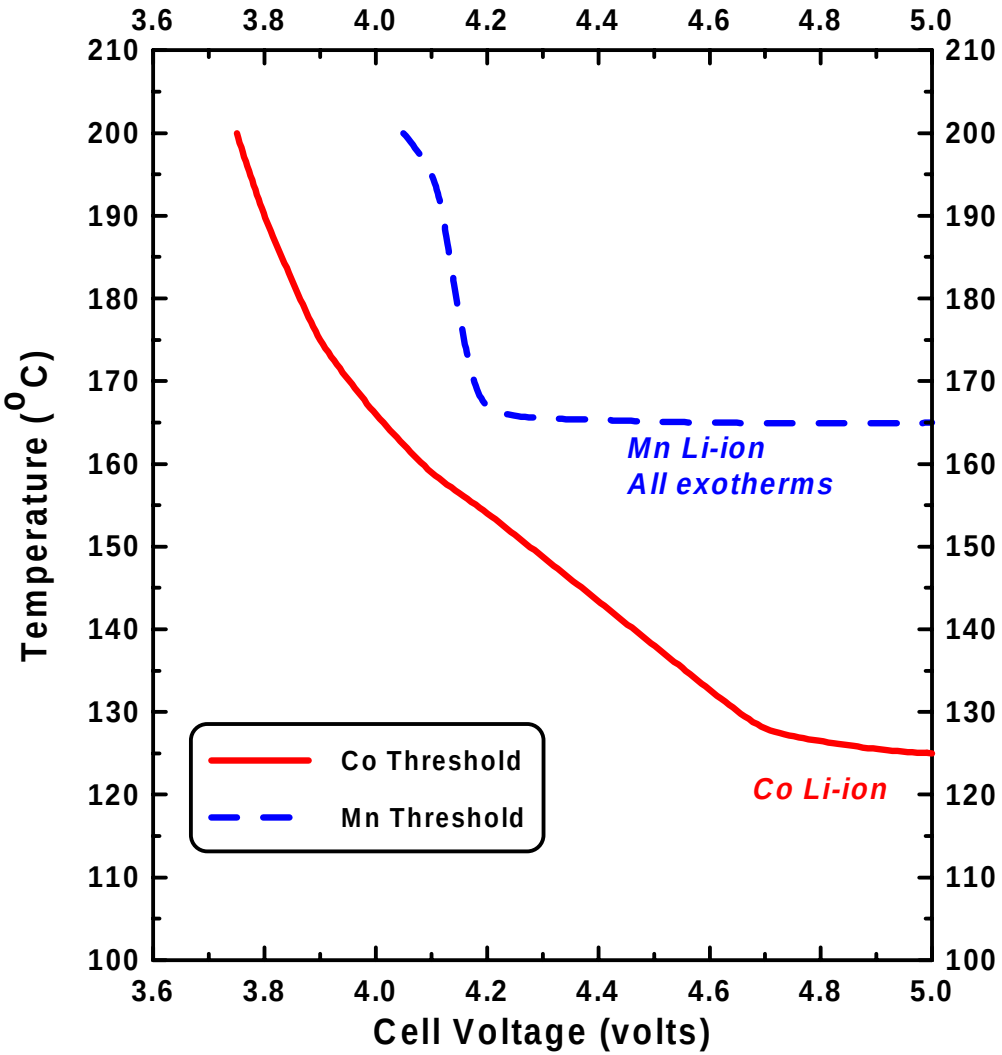
Charge Characteristics - $LiCoO_2$



	Discharged		Charged		Overcharged
Cathode	$2LiCoO_2$	⇨	$2Li_{1/2}CoO_2$	⇨	$2CoO_2$
Anode	C_6	⇨	LiC_6	⇨	$LiC_6 + Li$

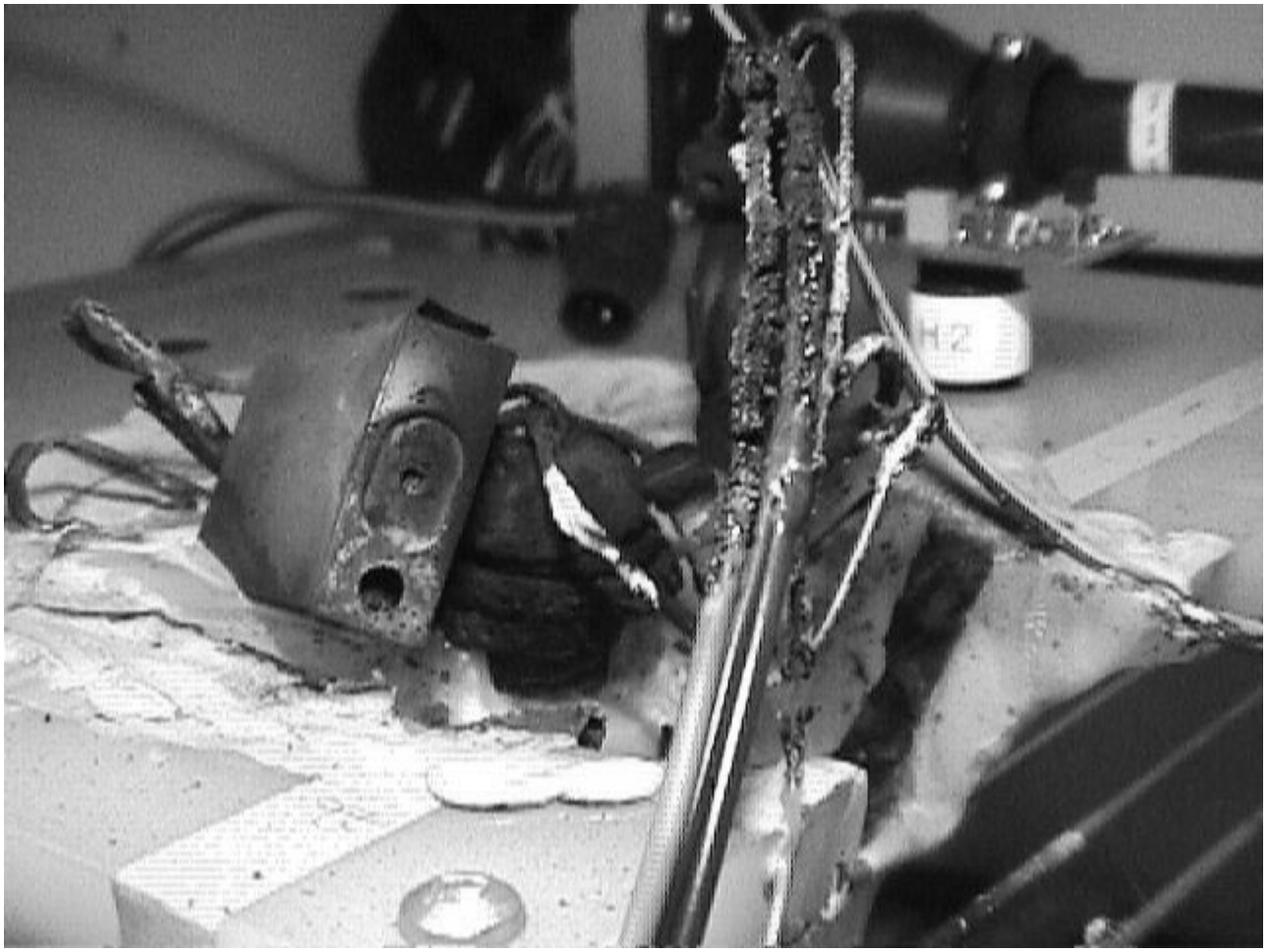
Cell Safety - Voltage vs Temperature

- This graph shows a cells tolerance to temperature when charged to progressively higher voltages.
- Points falling above the threshold represent cells that reach thermal run away.

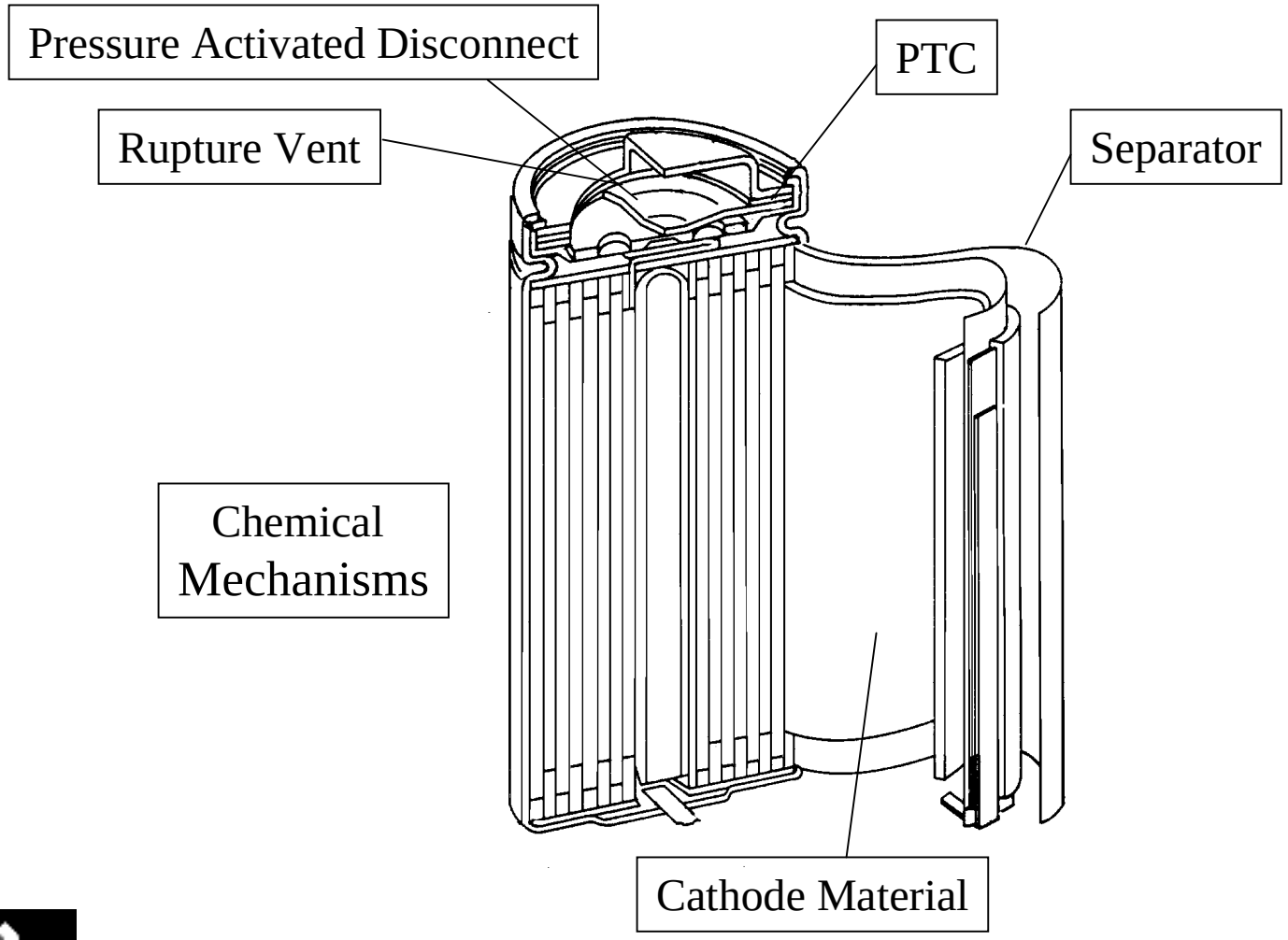


Dr. Jan Reimers et, al. Journal of the Electochemical Society

What Happens on Overcharge



Built in Cell Safety Mechanisms



Built in Cell Safety Mechanisms

- **Separator**
  - Plastic porous separator material between the anode and cathode electrodes, melts between 120'C and 150'C and the pores close disabling the cell.
- **Disconnect Device**
  - All cylindrical and some prismatic Li-ion cells have a built in electrical disconnect device (switch) for over-charge protection. This device is usually pressure activated on overcharge and permanently opens the electrical connection to the outside. This stops the overcharge before a possible safety incident.

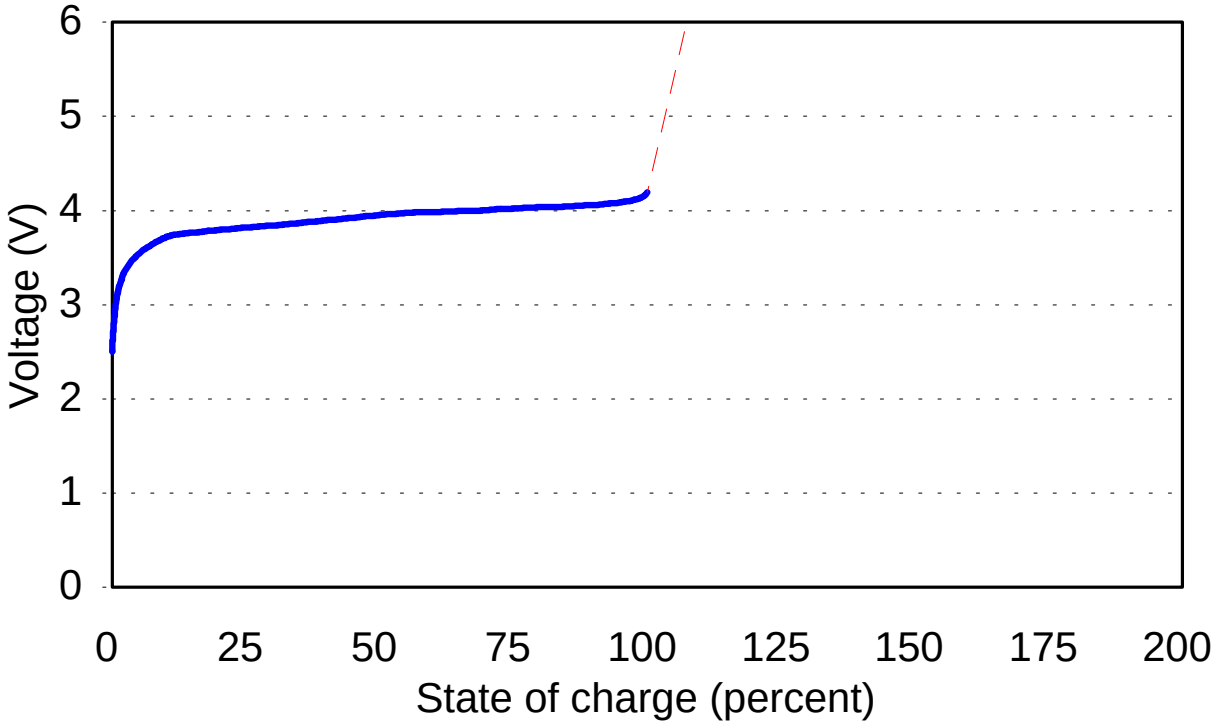
Built in Cell Safety Mechanisms

- **PTC (Polyswitch™)**
  - Usually built into the header of a cylindrical cell.
  - Used to limit currents in an over-charge condition (tripped by heat).
  - Also used to limit short circuit currents from a single cell to a safe level.
- **Rupture Vent**
  - In case of large internal pressure buildup (under thermal or mechanical abuse situations) safely releases the gas pressure, the cell doesn't explode.
- **Chemical**
  - Biphenol (NEC Moli Energy)
    - A voltage triggered polymer which causes the cell to go high resistance after overcharge. Increases cells safety to mechanical or thermal abuse after overcharge.

Built in Cell Safety Mechanisms

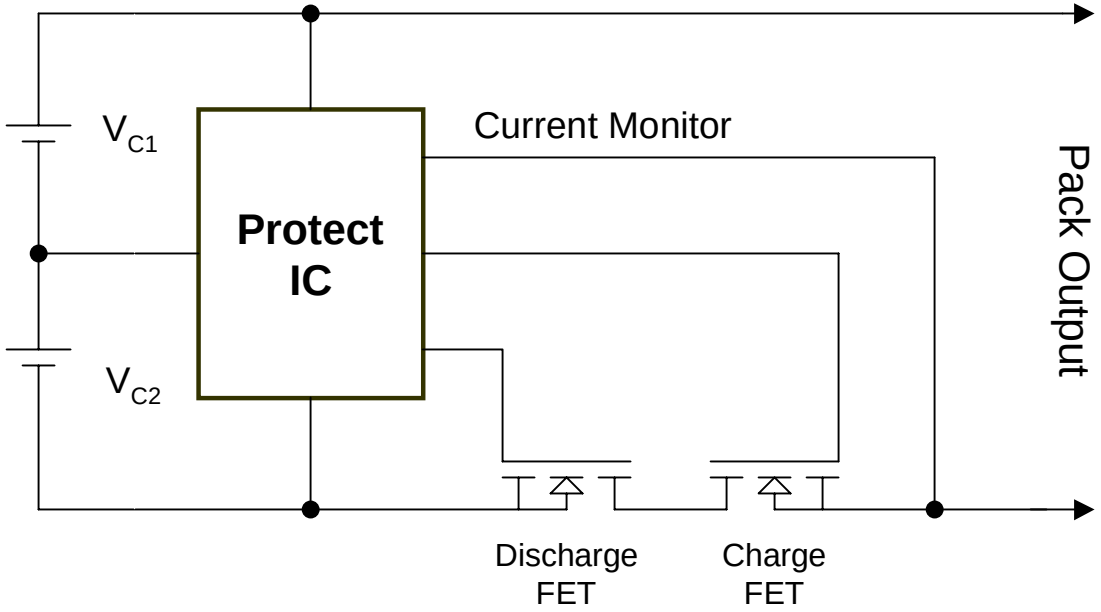
- **Cathode Material - $LiMn_2O_4$**
  - An overcharged Manganese cell is not much different than a normally charged cell.
  - For $LiMn_2O_4$, essentially all Lithium is removed from the cathode during normal charge (little excess lithium).
  - Overcharging $LiMn_2O_4$ cells above their designed charge voltage will cause;
    - Minimal lithium plating on the Anode.
    - The cathode material remains stable. Mn_2O_4 will not liberate oxygen until above 500 degrees C.
    - **Heat**
  - The cell still has a flammable electrolyte, but has more stable anode and cathode materials.

What Happens on Overcharge - $LiMn_2O_4$



	Discharged		Charged		Overcharged
Cathode	$2LiMn_2O_4$	⇨	Mn_2O_4	⇨	Mn_2O_4
Anode	C_6	⇨	LiC_6	⇨	LiC_6

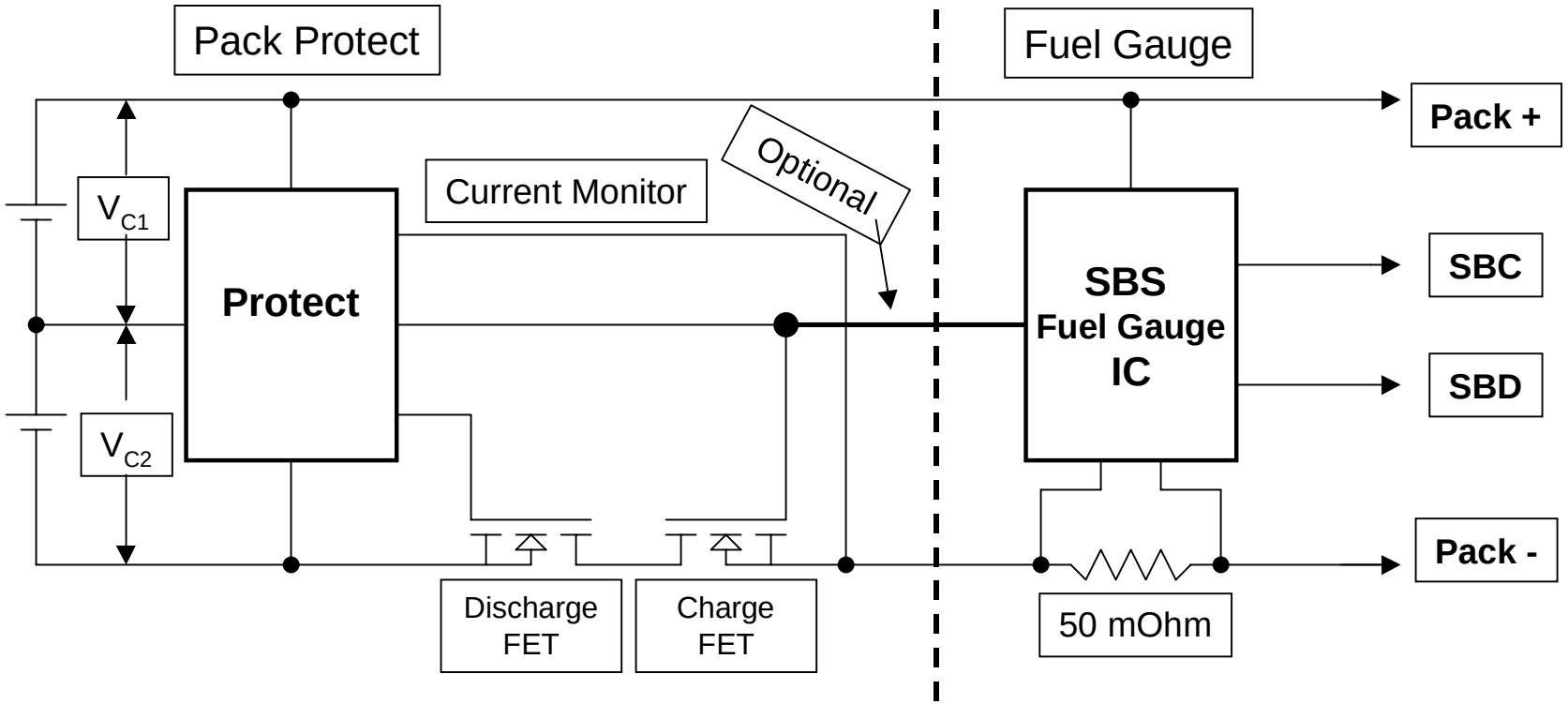
Pack Protection Circuitry



- Each Cell's voltage is monitored Individually (V_{C1}, V_{C2})
- Current is monitored through FET's
- One FET Disconnects on **Over Charge**
- Another FET Disconnects on **Over Discharge**

Protection / Fuel Gauge Circuitry

- Redundancy
  - Always use an independent pack protect IC
  - SBS Gauge may monitor FET status and send an error message to the host and charger to prevent overcharge.



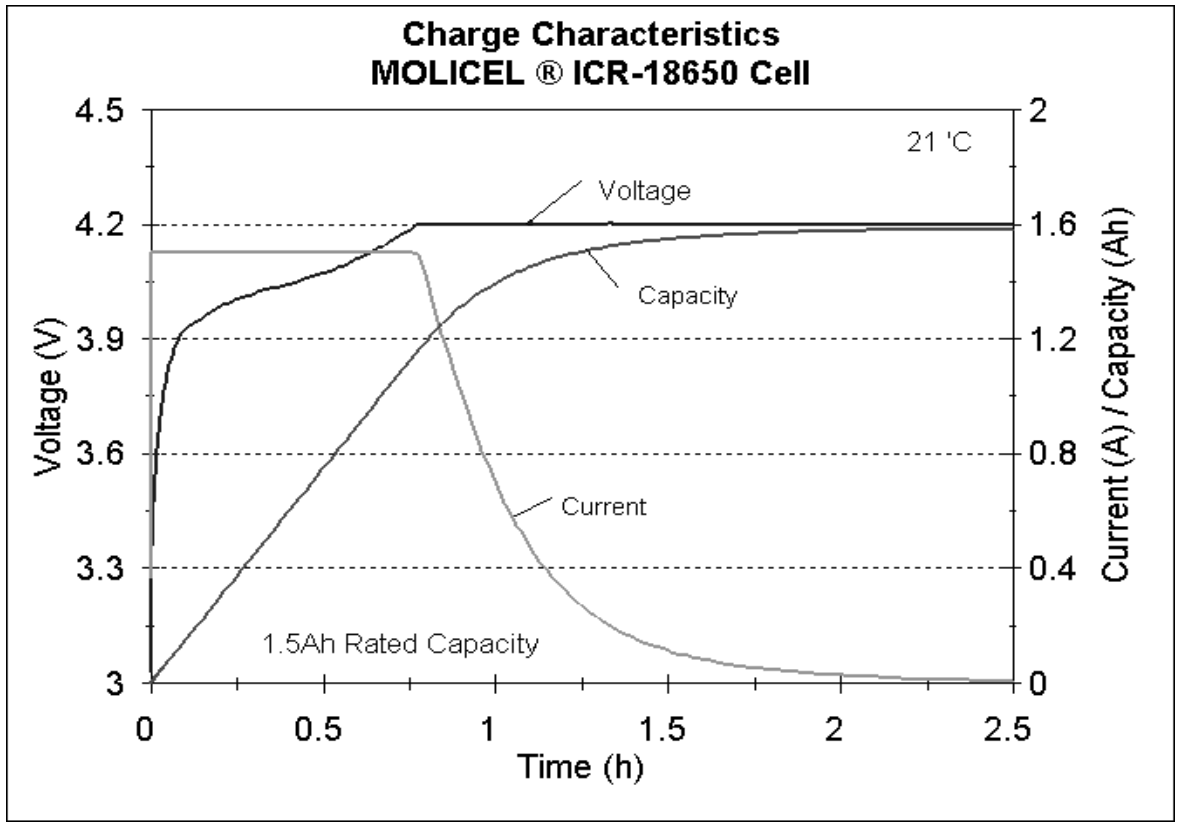
Additional Pack Protect Devices

- **PTC**
  - **Used as an additional device for short circuit protection. This device limits the current to and from the cells if the pack protect fails.**
- **Thermal Fuse**
  - **Placed in between cells to monitor temperature. If the cell temperature becomes to high, fuse will disconnect permanently. This device will disable charging in a case where the pack protect circuit fails on charge.**

Charging Lithium-ion Batteries

- Constant Current, Constant Voltage (CCCV)
  - Most common method of charging Lithium-ion cells.
  - Charge is terminated at some minimum current.
  - Current is limited to 1C.
  - Approximate charging time 2.5 hours.
- Pulse Charging
  - Charge control is inside battery pack.
  - Battery pack is supplied with a constant current source.
  - Charge times can be reduced.
  - Pulse charging can reduce cycle life of Lithium-ion batteries.

Charge - Constant Current, Constant Voltage



- Most common charge method for Lithium-ion batteries.
- Charge is terminated when the current tapers below a preset value (50-100mA/cell).
- Battery charges to 70-80% of capacity in one hour. Full charge takes about 2.5 hours.

Charging Safety Issues

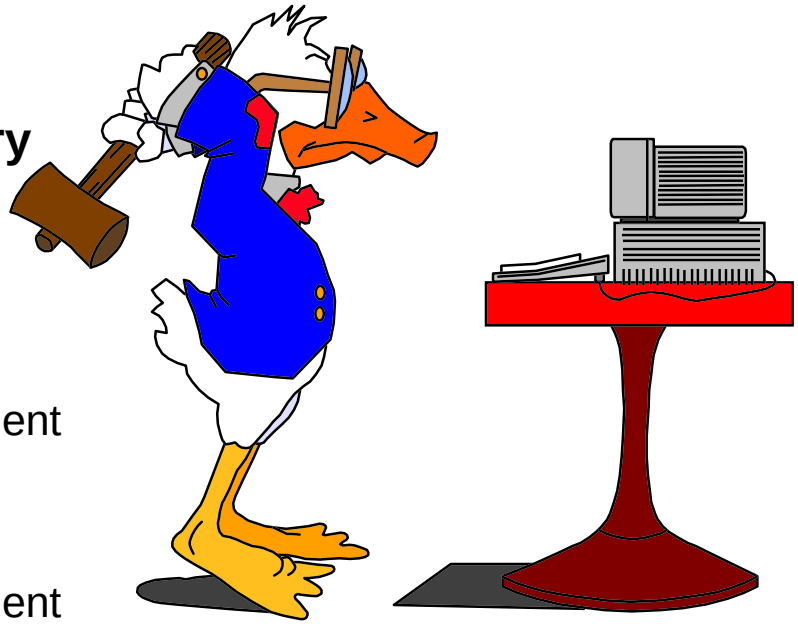
- **Charging over 1C.**
  - High charge currents can cause Lithium plating.
- **Terminate charge, limit voltage.**
  - Lithium-ion cells do not have a chemical shuttle mechanism like Nickel based chemistries. Charging over the specified charge voltage will decrease the safety of the cell in secondary abuse situations.
- **Avoid charging at low temperatures.**
  - Can cause lithium plating. Some manufacturers allow charging at low temperatures by reducing charging currents.

Discharging Safety Issues

- **Discharging below 0 volts can cause;**
  - Formation of copper shunt. If cell is driven negative long enough, a 0 ohm shunt will form and permanently disable the cell.
  - If shunt is only partially formed, charging at 1C rate will cause excessive heat. Therefore it is important to charge cells at C/10 rates if the cell voltage is low.
- **In a normal Li-ion battery pack the protection circuitry prevents the cells from being driven into reversal on discharge.**

Approvals

- **Cells**
  - UL1642
  - IEC
- **Battery Packs**
  - **USA - Underwriters Laboratory**
    - Individual Lithium-ion cells - UL1642, Safety Standards for Lithium Batteries.
    - Pack UL1950 - Safety of Information Technology Equipment
  - **Canada - CSA**
    - CSA C22.2 NO 950 - Safety of Information Technology Equipment
  - **Europe - TUV**
    - EN 60950 - Safety of Information Technology Equipment



SBS Battery Pack Safety Guideline

- **A SBS battery pack safety guideline is currently under development.**
- **Input from other SBS member companies is welcome and appreciated.**