Battery Basics, Cell Chemistry, and Cell Design

Battery Basics

What is a battery?

A device that converts the chemical energy of its cell components into electrical energy. It contains two materials that cannot undergo an oxidation-reduction reaction directly, but that can do so if electrons are allowed to travel from one material to the other through an outside circuit while ions simultaneously travel within the cell.

Battery Basics

Cell vs. battery:

A "cell" is one basic electrochemical unit. It has a voltage (or "potential") that is defined by the chemistry.

A "battery" consists of one or more cells connected in series or parallel.

Battery Basics

Other terms:

Potential (voltage) – measured in volts. The open circuit voltage is defined by the chemistry (i.e., the active materials). It is independent of the size of the battery.

Current – measured in amps. This corresponds to the rate at which electrons can be removed from the battery. The current capability of a battery depends on the cell design and the chemistry.

Power – measured in watts. This is the product of the potential and the current: for a given current, the higher the voltage, the higher the power.

Capacity – usually measured in amp-hours. This is a measure of the number of electrons that can be removed from the battery. The capacity is proportional to the size of the battery.

Battery Basics

All batteries contain:

Anode - negative electrode

A material that undergoes oxidation during the cell discharge.

Cathode - positive electrode

A material that undergoes reduction during the cell discharge.

Electrolyte - medium for ion transfer

A medium, usually liquid, through which ions move from one electrode to the other during the cell discharge. An ionic species, the electrolyte salt, is dissolved in the electrolyte.

Battery Basics

Some familiar batteries:

Alkaline (used in toys, flashlights, etc.)

Anode – zinc

Cathode – manganese dioxide

Electrolyte – KOH in water

Voltage (open circuit) – 1.5 to 1.6 V

Mercuric oxide (formerly used in hearing aids)

Anode – zinc

Cathode – mercuric oxide

Electrolyte - KOH or NaOH in water

Voltage (open circuit) – 1.35 V

Battery Basics

Note that in most familiar battery types, the anode and the cathode are solid materials, and the electrolyte is a liquid that does not undergo reaction as the cell is discharged.

Electrochem primary lithium batteries, by contrast, use liquid cathodes.

Battery Basics

Lithium batteries: Any battery that uses lithium metal as the anode material is a lithium battery.

Some examples:

Li/MnO_2 – used in cameras, watches, etc.

Li/SO_2 – widely used in military applications (radios, etc.)

Li/FeS_2 – available from Energizer, a lower voltage system that can be used as a drop-in replacement for alkaline cells

- Lithium is an extremely reactive metal. In all lithium batteries, the lithium reacts with the electrolyte to form a passivation layer (the "SEI") that prevents further reaction.
- Lithium melts at 180 C. When the lithium melts, the passivation layer is destroyed, and the battery is very likely to burn or explode.

Battery Basics

Lithium Batteries made by Electrochem

Cell Classification	Power Capability	Typical Cathodes
Liquid Cathode	Moderate to high	$SOCl_2$, SO_2Cl_2 $SOCl_2 + Br_2/Cl_2$
Solid Cathode	Low to moderate	MnO_2, $(CF)_n$ SVO
Solid Electrolyte	Very low	I_2 (PVP)

Battery Basics

All of the current Electrochem products use a "liquid cathode."

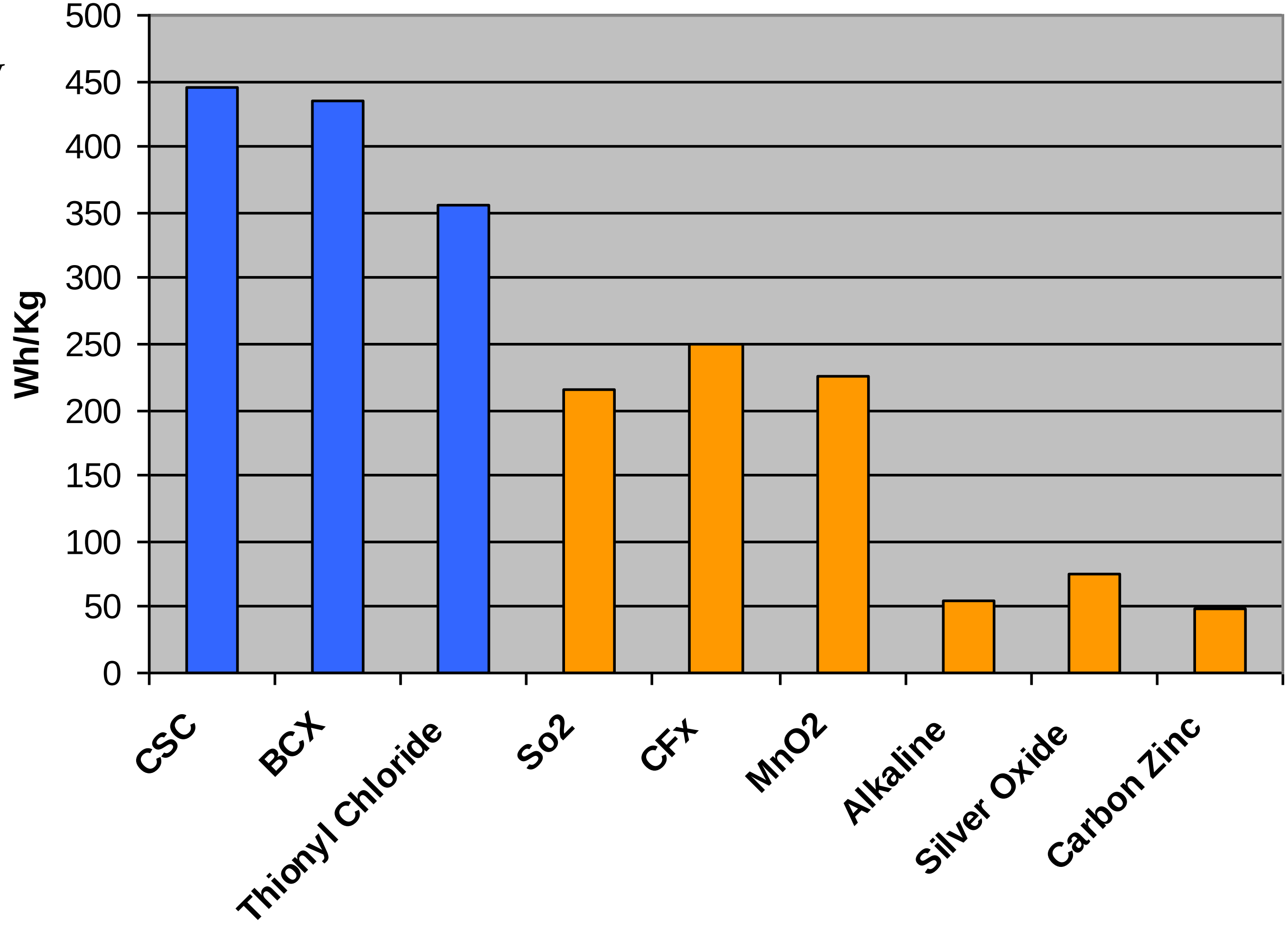
In liquid cathode systems, the active cathode material is a liquid that also acts as the electrolyte.

A porous carbon material serves as the site at which the reduction of the active material takes place. The carbon itself does not undergo reaction in this process.

The lithium liquid cathode systems have a very high open circuit voltage (3.6 V or 3.9 V) that contributes to their extremely high energy density.

Energy Density

C Size Energy Density Comparison



Battery Chemistry

Advantages:

- The liquid cathode systems provide the highest energy density (Wh/L or Wh/g) of any commercially available battery systems.
- They can operate over an extremely wide temperature range (-55 C to 200 C).
- These systems have a very low rate of self-discharge (typically <2% per year at room temperature).

Battery Chemistry

Disadvantages:

- Because the electrolyte is so reactive, the passivation layer that forms on the lithium is relatively thick. As a result, liquid cathode systems are subject to significant voltage delay (i.e., voltage drop when a load is applied after long storage).
- Because of the very high energy density and high reactivity, liquid cathode batteries must be handled with care!
- The liquid electrolytes are strong oxidants and highly reactive with water. They are very hazardous!
- However, when the batteries are properly treated after use, the end products are environmentally friendly (simple inorganic salts, with no heavy metals such as lead or cadmium).

Battery Chemistry

Electrochem makes three different types of liquid cathode primary cells:

- thionyl chloride
- sulfuryl chloride (CSC)
- bromine chloride (BCX)

Within each chemistry family there are electrolyte variations using different electrolyte salts (aluminum-based or gallium-based), and different concentrations of these salts.

The electrolytes are optimized for particular applications.

Battery Chemistry

Lithium / Thionyl Chloride

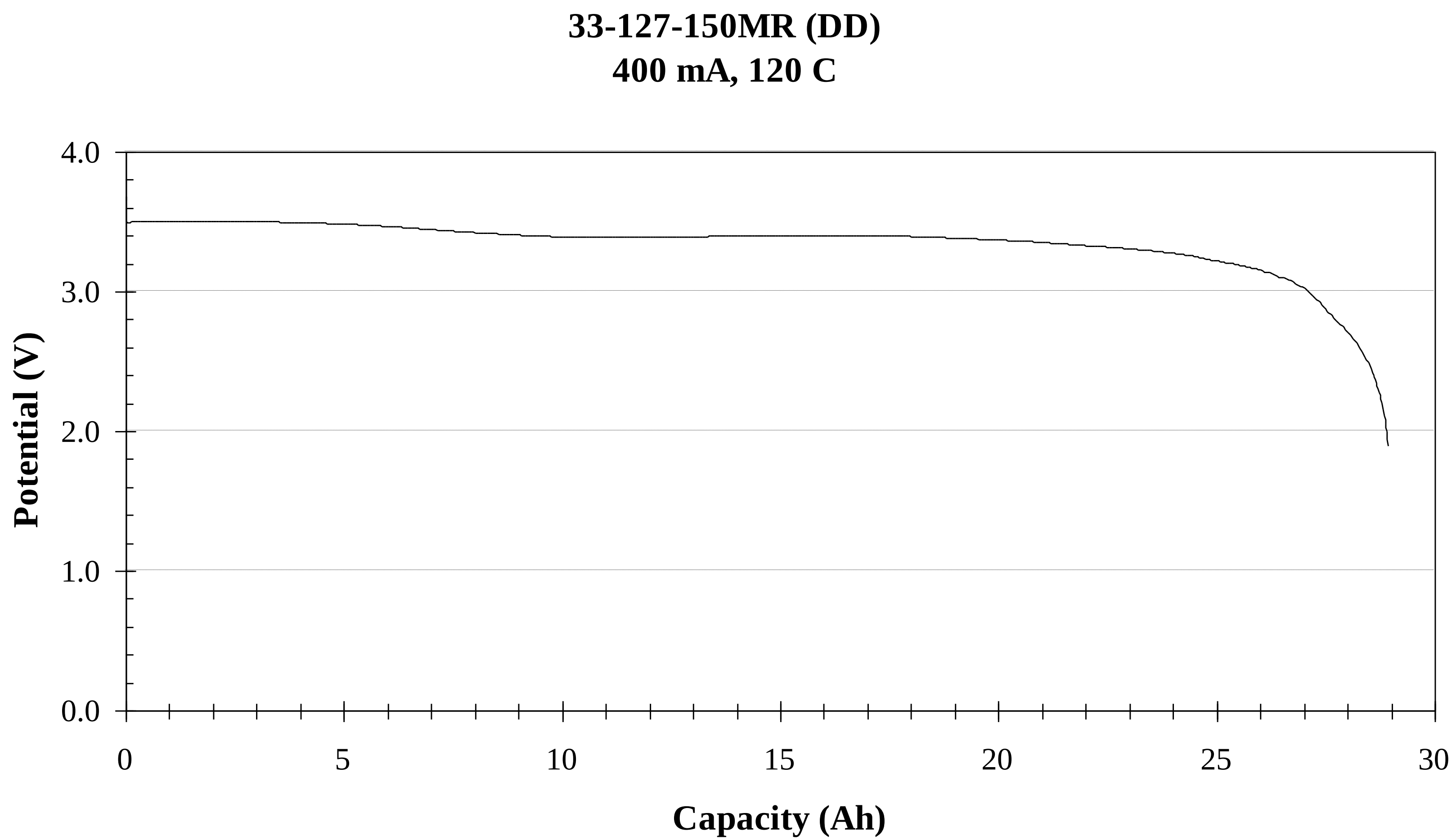
Anode Oxidation: $Li \rightarrow Li^{+} + e^{-}$

Cathode Reduction: $2SOCl_2 + 4e^{-} \rightarrow S + SO_2 + 4Cl^{-}$

The open circuit cell voltage of $Li/SOCl_2$ cells is 3.65 V.

Thionyl chloride is the most widely used of the liquid cathode electrolytes. It can be used over the full temperature range.

Battery Chemistry



Battery Chemistry

Lithium / Sulfuryl Chloride ("CSC")

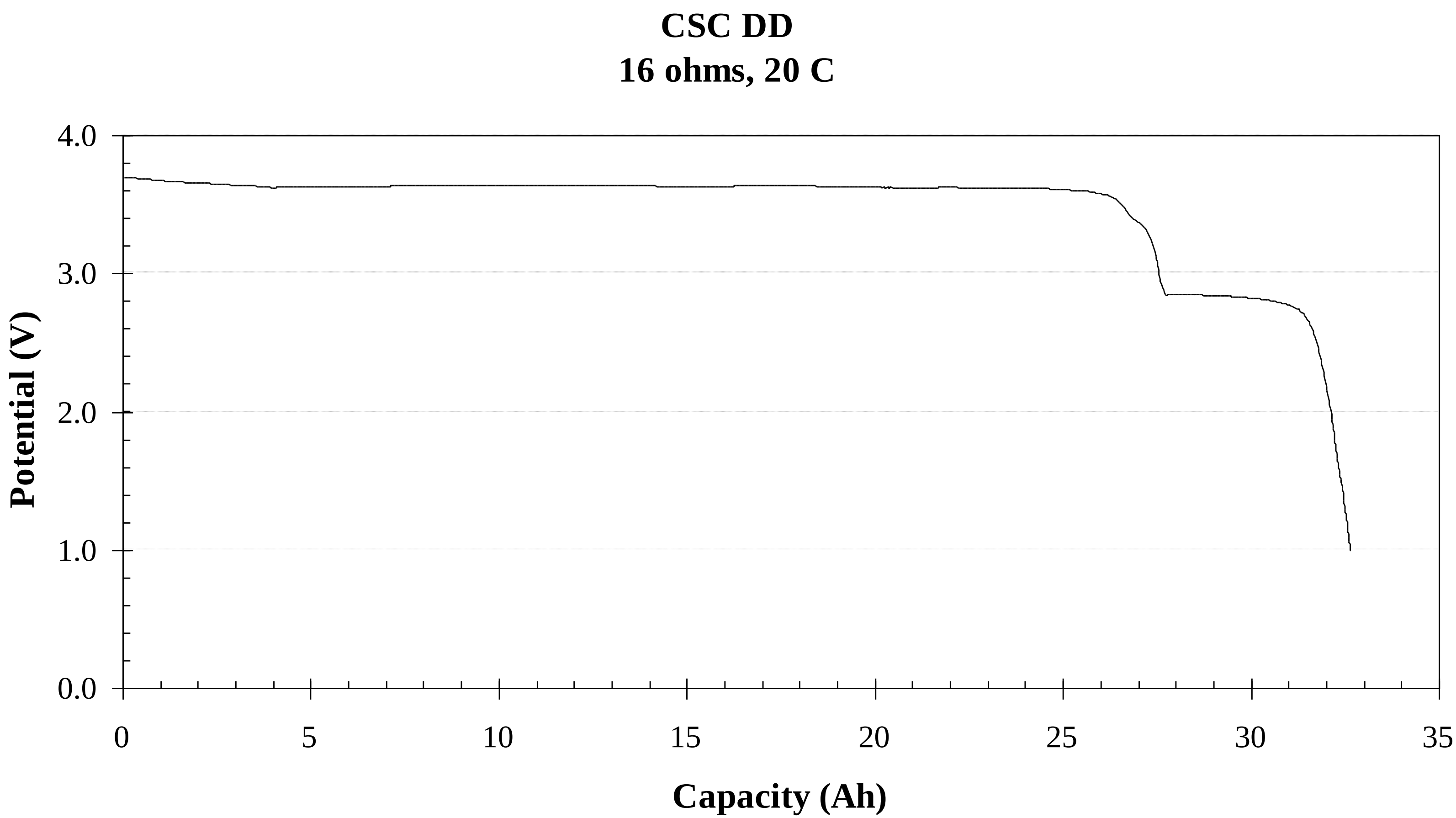
Anode Oxidation: $Li \rightarrow Li^{+} + e^{-}$

Cathode Reduction: $SO_2Cl_2 + 2e^{-} \rightarrow SO_2 + 2Cl^{-}$

The open circuit cell voltage of Li/SO_2Cl_2 cells is 3.93 V.

The CSC cells have the highest energy density of the Electrochem products. They have excellent rate capability, but do not work well at the coldest temperatures (<-20 C).

Battery Chemistry



Battery Chemistry

Lithium / "BCX"

Anode Oxidation: $Li \rightarrow Li^{+} + e^{-}$

Cathode Reduction:

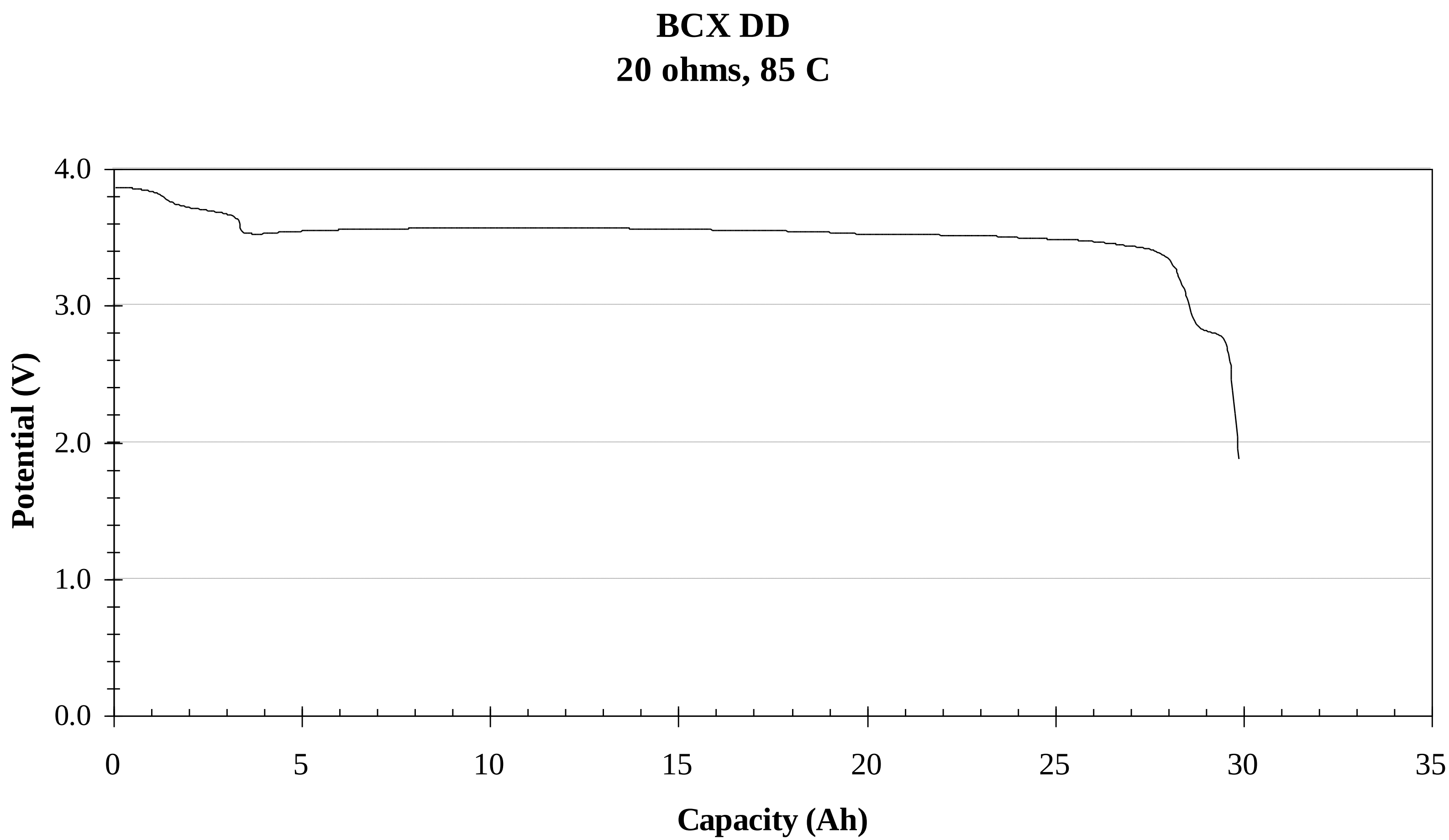
$$BrCl + 2e^{-} \rightarrow Br^{-} + Cl^{-}$$

$$2SOCl_2 + 4e^{-} \rightarrow S + SO_2 + 4Cl^{-}$$

The BCX electrolyte is a thionyl chloride electrolyte to which a bromine-chlorine complex is added. The open circuit cell voltage of $Li/SOCl_2$ cells is initially 3.9 V.

BCX cells operate well at the coldest temperatures. The electrolyte was developed for improved safety in the case of deep discharge and overdischarge.

Battery Chemistry



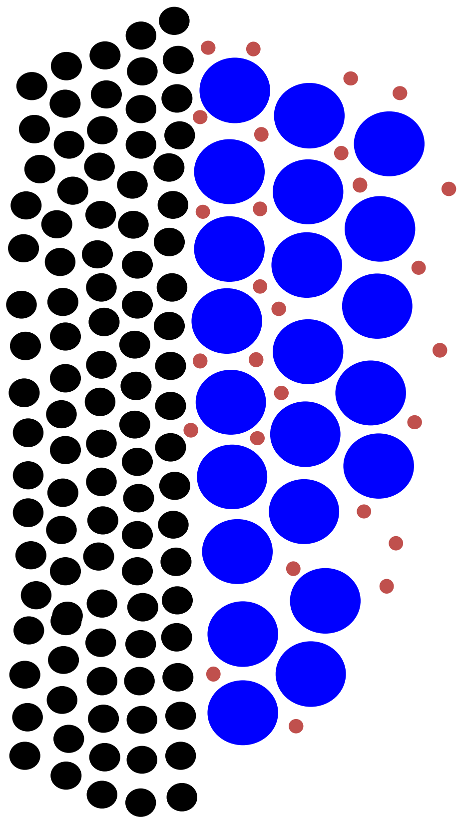
Passivation

In a liquid cathode cell, the active cathode material is always in contact with the lithium anode. Instantaneous reaction between the anode and the liquid cathode leaves a layer of reaction products (mostly lithium chloride) on the anode surface.

This LiCl layer "seals" the lithium surface, protecting the lithium from further reaction with the cathode.

Without the LiCl layer, this type of cell could not exist.

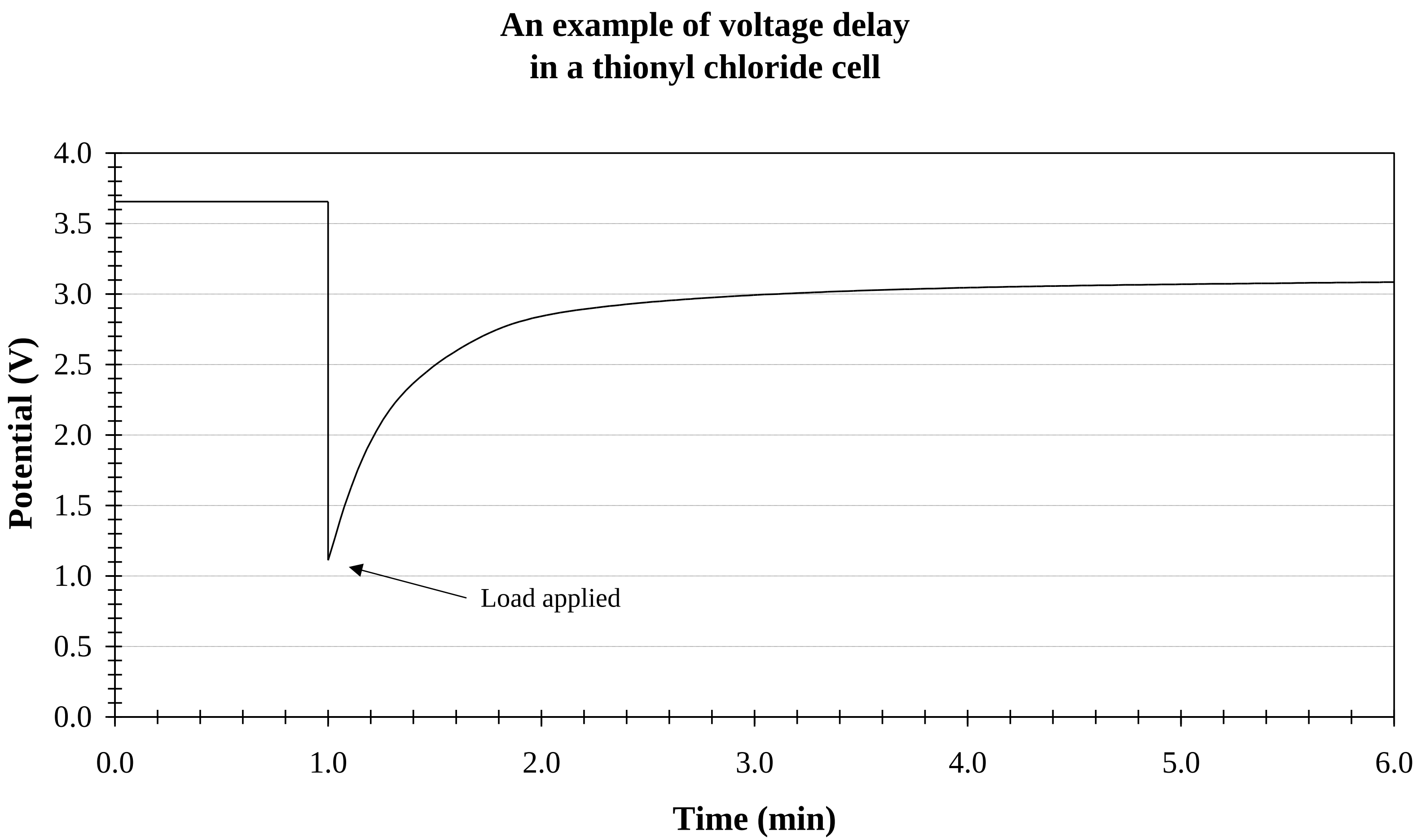
Passivation



Under some conditions, the LiCl passivation layer can lead to a phenomenon known as “voltage delay” – a dip in running voltage at the onset of load. As the discharge continues, the passivation layer breaks down and the voltage returns to normal.

The extent of passivation depends on the length of storage and the storage temperature. If necessary, the passivation layer can be removed by pre-loading the cell.

Passivation



Passivation

Friend or foe?

- Without the passivation layer, liquid cathode systems could not exist.
- The passivation layer helps keep the self-discharge rate extremely low.
- But excessive passivation can lead to voltage delay.

Cell Design

Electrochem designs and manufactures primary lithium cells with three different electrode configurations: bobbin, moderate rate (dual anode), and spirally wound.

The amount of current that a battery can deliver depends on the surface area of the electrodes. A spirally wound arrangement of two flat electrodes with high surface area gives much higher rate capability than the same amount of material arranged in a compact bobbin form.

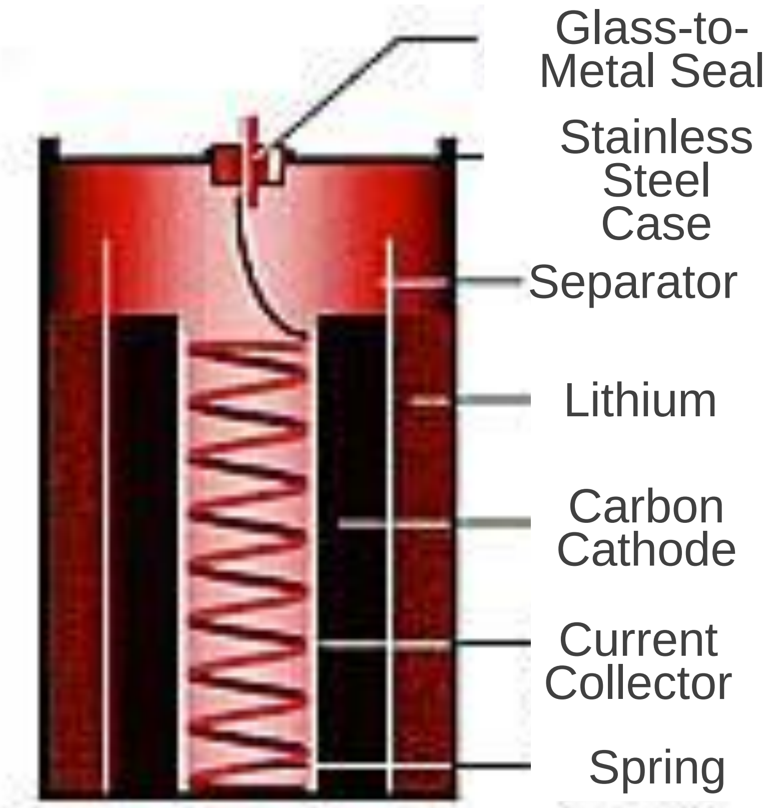
However, the spirally wound configuration is not as rugged for conditions of high shock and vibration as the simpler bobbin and moderate rate configurations.

Cell Design

Bobbin cells have low electrode surface area, and are therefore capable of delivering only low current, typically in the micro-amp to milli-amp range, depending on cell size. Bobbin cells are often used for memory backup and other low current / low power applications.

Electrochem's "QTC85", "100", "180" and "200" series cells use a bobbin electrode configuration.

Cell Design



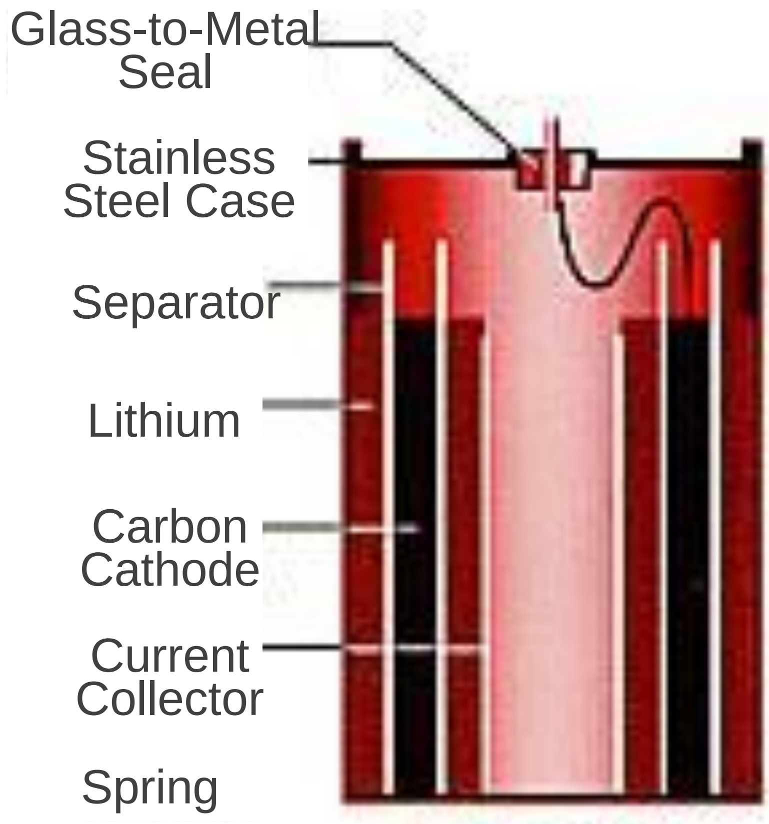
Bobbin (Low Rate)

Cell Design

Moderate rate cells have an electrode surface area roughly twice that of a bobbin cell, and are capable of delivering moderate continuous current, typically in the milliamp range, but as high as 1 amp for larger cells. Moderate rate cells are used in a wide array of applications, but are most prevalent in the downhole petroleum industry.

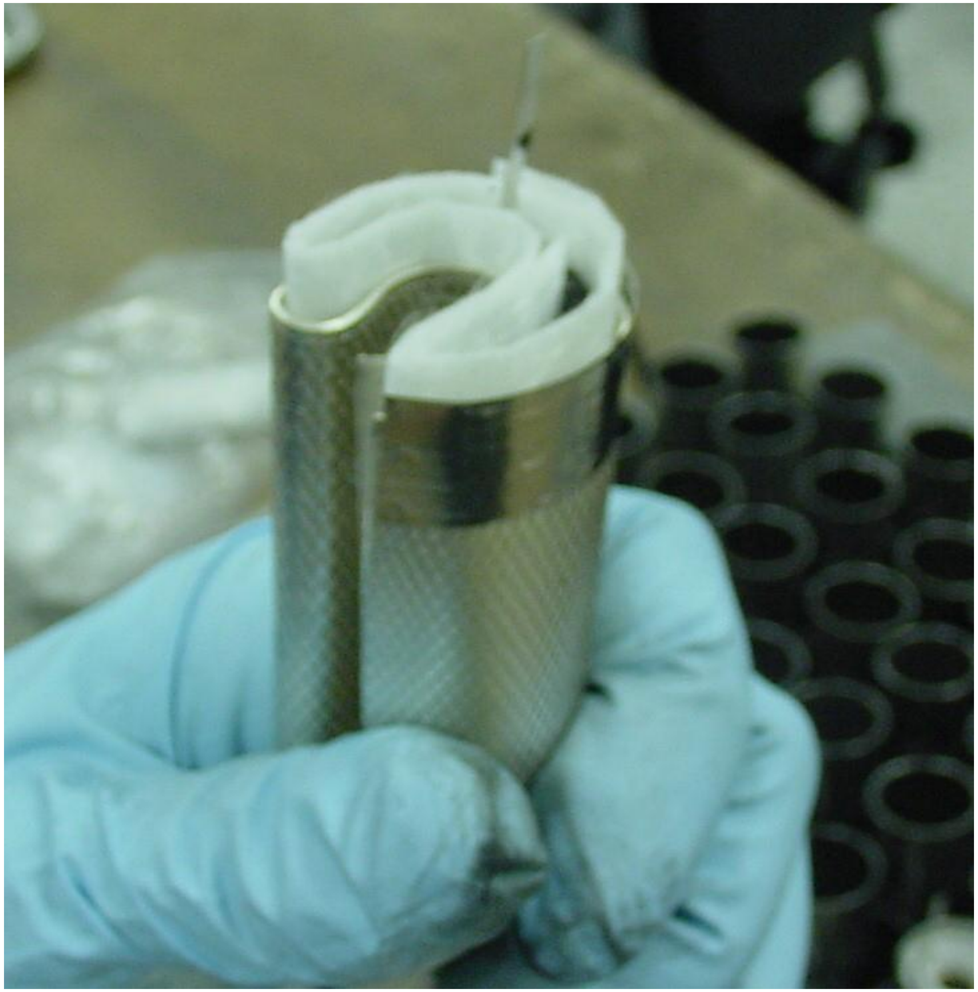
Electrochem's "150MR", "165MR", "180MR" and "200MR" series cells use a dual anode electrode configuration.

Cell Design

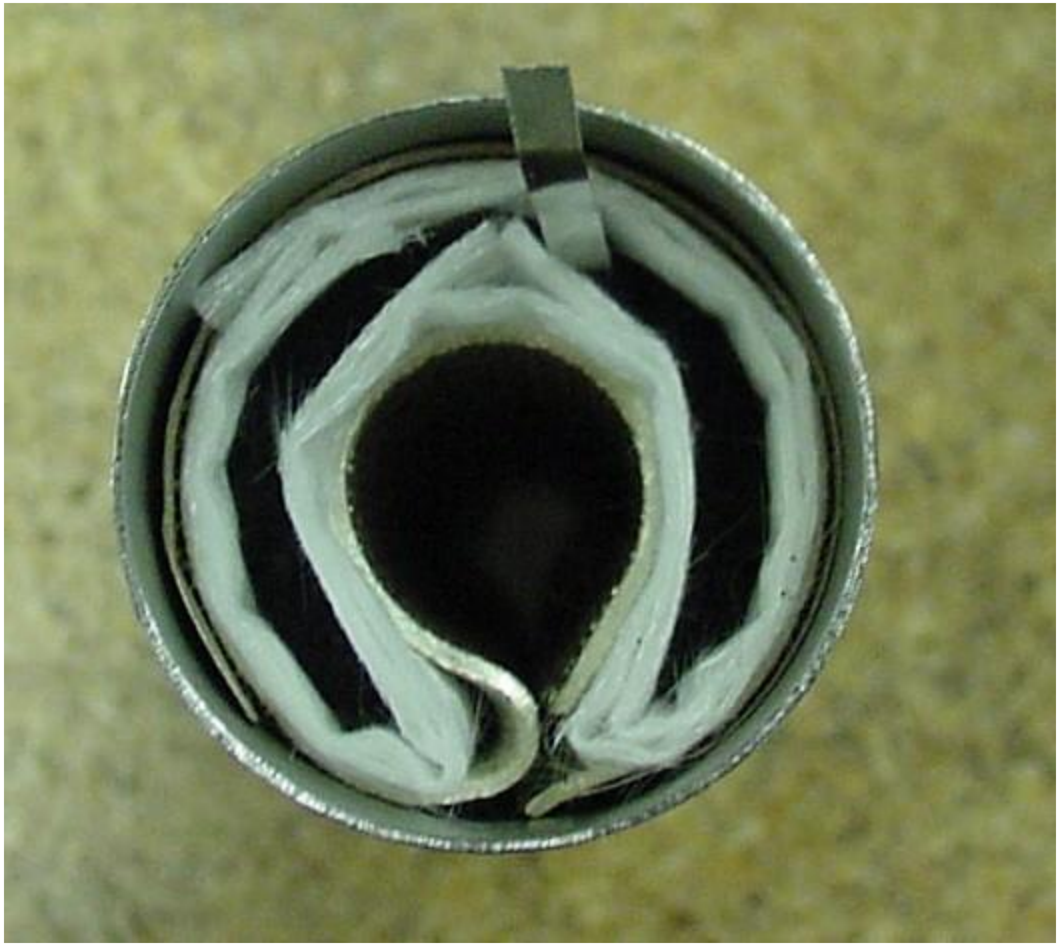


Moderate Rate

Cell Construction



Cell Construction

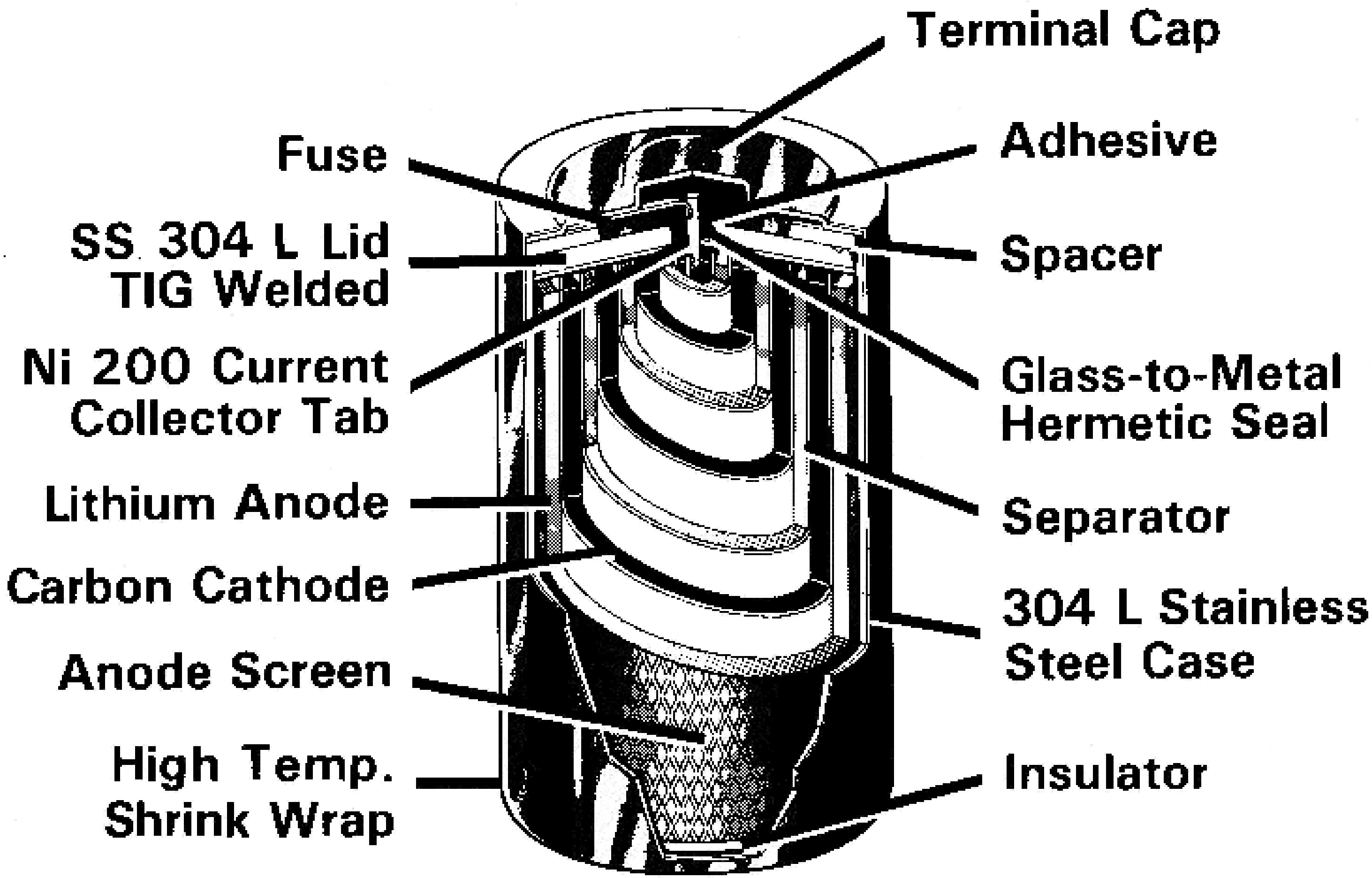


Cell Design

Spirally wound cells have a relatively high electrode surface area and are therefore capable of delivering higher continuous and pulse current, ranging from several hundred milliamps for smaller cells to several amps for larger cells. Spirally wound cells are used in a wide array of applications, including oceanographic, military, aerospace, pipeline inspection and more.

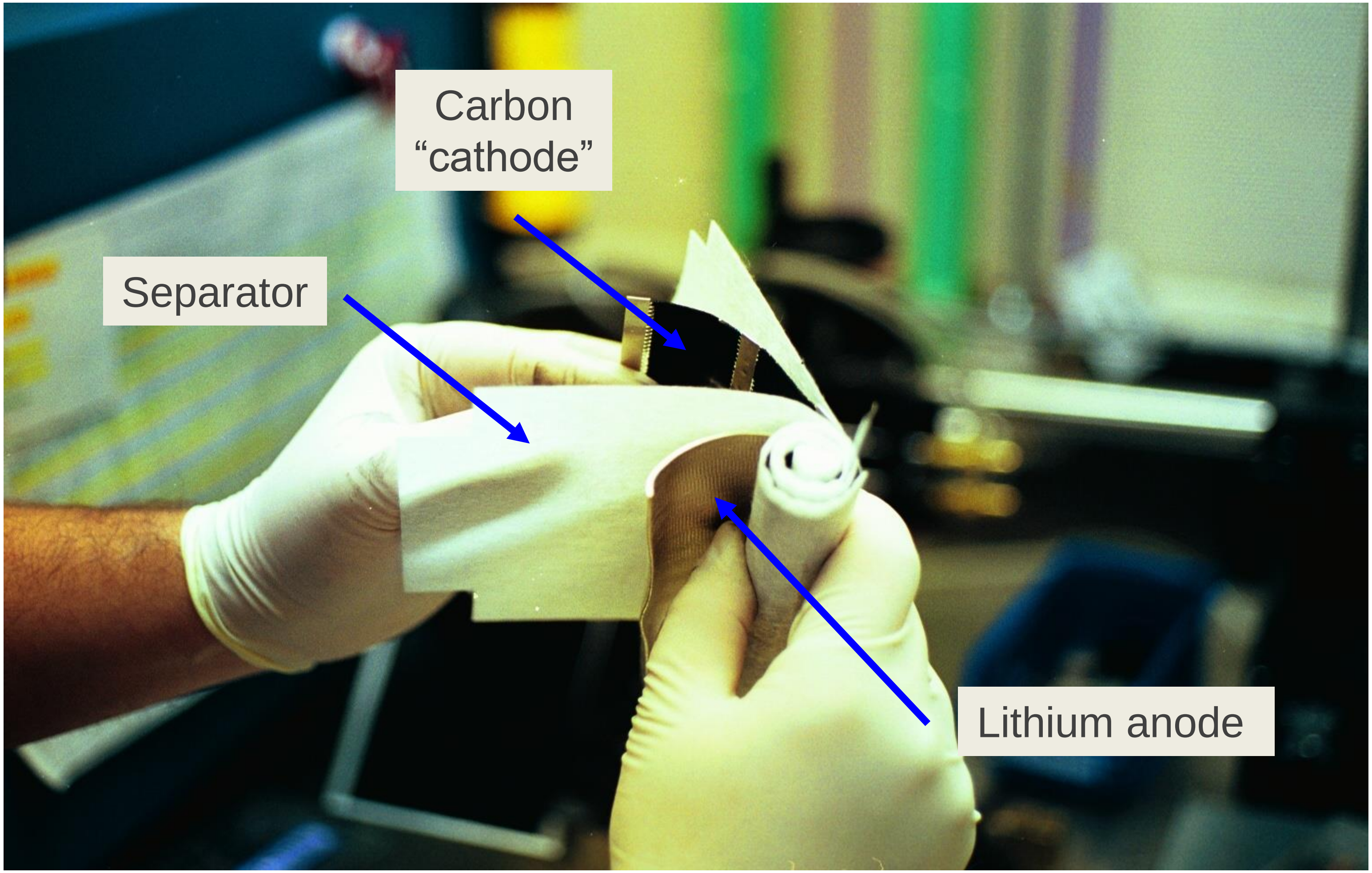
Electrochem's "BCX85", "CSC93", "PMX150/165", MWD150 and "VHT200" series cells use a spirally wound electrode configuration.

Cell Design



Terminal Cap
Fuse
Adhesive
SS 304 L Lid
TIG Welded
Spacer
Ni 200 Current
Collector Tab
Glass-to-Metal
Hermetic Seal
Lithium Anode
Separator
Carbon Cathode
304 L Stainless
Steel Case
Anode Screen
High Temp.
Shrink Wrap
Insulator

Cell Design



Cell Design

Cell designs for higher temperatures

Cells that operate at higher temperatures must be designed to handle higher internal pressure. The cell hardware (can and cover) must be heavier or otherwise designed to prevent breakage of the glass-to-metal seal. Additional headroom is also required to allow for electrolyte expansion.

The "PMX" series uses the same sulfuryl chloride chemistry as the "CSC" series, but is designed for use up to 150 C or 165 C. (The CSC cells are rated to 93 C.)

Similar design considerations hold for the 150 C and 165 C versions of the MR series.

Cell Design

Lithium alloy cells

Lithium-magnesium alloys that melt at higher temperatures than pure lithium metal are used in the 180MR and 200MR series, as well as the spirally wound VHT cells, which are rated to 200 C.

These cells are optimized for use at the very highest temperatures (150 C to 200 C). **Lithium alloy cells give very poor performance below 70 C.** This performance limitation must be taken into account when these cells are used.

Cell Design

- The cell cases and covers are made of stainless steel (304L or 316L).
- Most of the cells use nickel current collectors and internal tabs.
- Cells with low magnetic signature are available. The LMS cells use stainless steel current collectors and tabs.

Cell Design

Other Design Considerations

Pressure Capability

- The cells are hermetically sealed; the cover is welded to the case.
- The positive and negative contacts are separated by a glass-to-metal seal.
- The glass-to-metal seal will fail under a pressure differential of approximately 1000 psi.
- The cells can easily withstand a full vacuum.
- An interesting independent discussion of failure modes under high external pressure is available: Ø. Hasvold, et al., Proc. 42nd Power Sources Conf., Philadelphia, PA, 2006, pp. 75-78.

Cell Design

Other Design Considerations

Safety Devices

- Electrochem products are provided with electrical safety devices at the cell level and/or the pack level as appropriate.
- All of the spiral wound cells include a fuse (or PTC) to prevent hazardous behavior in case of a short.
- Do not attempt to replace the fuse or otherwise modify the cell termination!
- A cell with a blown fuse will typically show an OCV of 0.0 V. However, some fuses have a very high resistance when they have blown; this can lead to an apparent low OCV that is greater than 0 V.

Thank you!