Handbook On Lithium Battery Pack Design

An Ebook on how to design your custom battery packs

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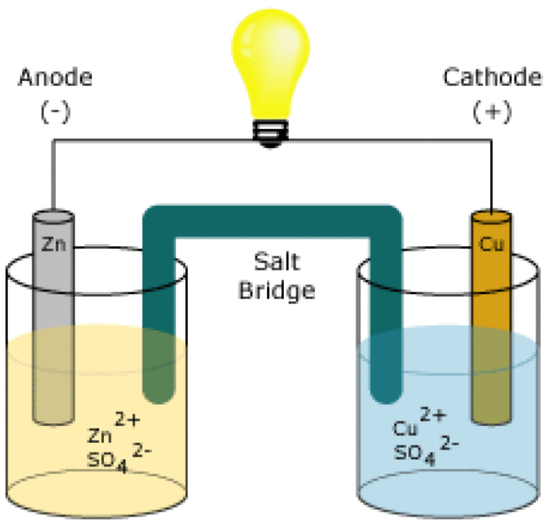
1 *Introduction of battery*

Battery Technologies – Overview

A "battery" is the generic term for an electrochemical source of electricity, which stores energy in a chemically bound form until converting it directly into electric power. A battery may either be a single cell or multiple cells connected in a series or parallel configurations.

Batteries are categorized as being either primary or secondary systems. For instance, primary batteries are commonly known as disposable batteries and are not engineered for recharging (doing so may result in an explosion). Conversely, secondary batteries are engineered so they can be safely recharged. This is owed to the fact that the anode and cathode discharge reactions are reversible. Properly designed, a secondary battery can be recharged hundreds or thousands of times.



Daniell Cell

The History of Battery Market

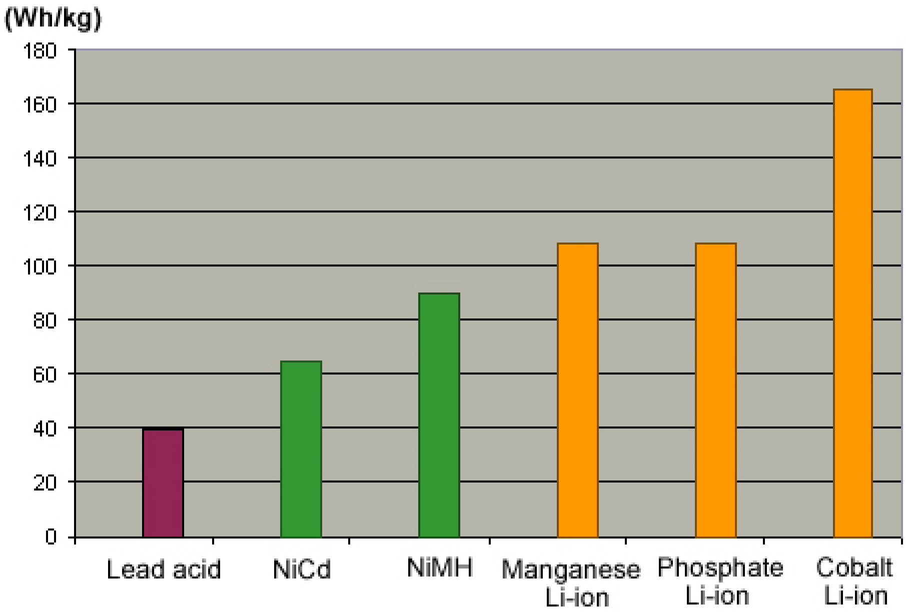
The use of lead-acid batteries (Pb/Ac) began in the nineteenth century. Because of low manufacturing costs, good performance and long life, the lead-acid battery is still the most common rechargeable battery system in the world, with a market share of as much as 40 to 45%. The lead-acid battery has a wide field of applications, and new manufacturing methods, cell designs and application areas are still introduced. Its most common use is as a starter battery in cars, with additional applications in industrial trucks and as reserve power. In the Electric Vehicle arena, Pb/Ac is well positioned to capture much of the emerging micro-hybrid market (start/stop hybrids).

NiCd batteries are a mature and thoroughly tested battery technology that was patented in 1899 by Waldemar Jungner. NiCd batteries are used in a wide variety of stationary, mobile and portable applications, ranging from large-scale backup power and start batteries for aircraft to handheld power tools and toys. Due tno stricter EU environmental legislation, NiCd batteries are expected to be gradually phased out in Europe, at least in consumer electronics applications.

However, NiCd batteries are expected to retain a strong position on several niche markets.

The NiMH battery uses relatively new battery technology developed in the early 1990s. NiMH batteries offer the same cell voltage as NiCd batteries, and can therefore replace them in many applications without modification. Cell voltage combined with higher energy density and better environmental properties are the driving forces that enabled NiMH batteries to capture market share from NiCd in consumer electronic products over the past decades.

Today, Li-ion batteries have completely taken over the computer and mobile phone battery markets, though portable NiMH batteries are expected to remain on the market as a low-cost alternative to lithium batteries.



Energy-Dense Lithium-ion Batteries

Li-ion batteries were introduced onto the market in the mid 1990s, soon replacing the NiMH batteries in mobile phones, notebook computers, and other portable electronic devices. At the present time, the use of lithium batteries has been widely spread to a number of cheaper consumer products.

The term lithium-ion battery refers to an entire family of battery chemistries. The common properties of these chemistries are that the negative and the positive electrode materials serve as hosts for lithium ions and that the battery contains a non-aqueous electrolyte. The chemical energy of lithium differs between the positive and negative electrodes. This difference governs the retrievable voltage from the battery. During charge and discharge, lithium ions are transported between the two electrodes and electric energy may be absorbed or released, when current flows through the cell.

Lithium-ion batteries have become the most common rechargeable batteries for consumer electronics due to their high energy densities, relatively high cell voltages, and low weight-to-volume ratios. They are also predicted to become commonplace for industrial, transportation, and energy-storage applications, even if they tend to be more expensive than equivalent battery technologies with aqueous electrolytes.

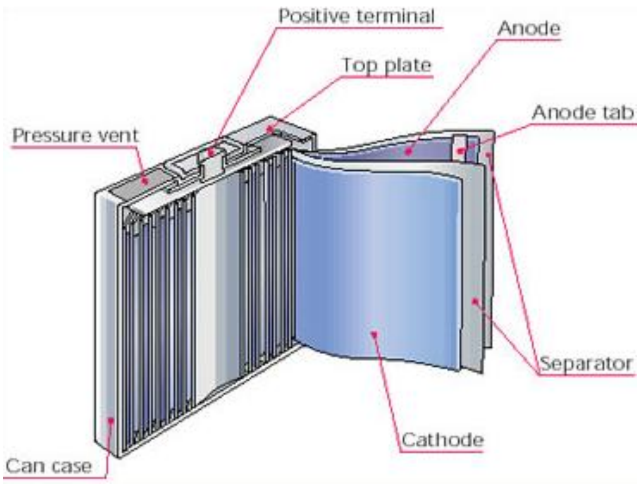
Li-ion batteries are still in a relatively early phase of development in relation to the energy storage industry, and have only been readily available for 15 years in the commercial market. This means that there is potential for both comprehensive technical development and price reductions.

Primary Lithium Batteries

Primary batteries have existed since the 1970s, are easy to use and provide convenient sources of energy for portable applications. The batteries usually require no or very little maintenance and they have a long shelf life; modern lithium batteries can usually be stored for up to 10 years, and there are special batteries with solid state electrolyte that can be stored for more than 20 years. The storage tolerance at elevated temperatures is generally good, in some cases up to 70°C.
The most common primary lithium batteries on the market are lithium disulphide ($LiFeS_2$) and lithium manganese dioxide ($LiMnO_2$) batteries. Both of these are of the solid cathode type and are sold as consumer batteries from electrical goods stores and supermarkets. Other primary lithium batteries are mainly intended for the professional market.

Secondary Lithium Batteries

There are two main groups of rechargeable lithium batteries, one of which uses lithium metal as the negative electrode. These are called lithium metal batteries. Lithium reacts with the electrolyte, forming dendrites on the surface of the electrode. Under repeated charging, the surface of the anode increases, with a corresponding increase in its re activity and thermal sensitivity. More recently, however, the lithium metal anodes have once again found practical application in research, although they have not yet been marketed on a large scale. One way of reducing the fire risk in lithium metal batteries is to replace the electrolyte with a solid state polymer electrolyte, that does not react with lithium.



The second type of rechargeable lithium battery is called a lithium ion battery, which has a negative terminal that consists of a carbon-based material, usually graphite, or another type of alloy or material that permits interrelation, i.e. storage, of lithium in the structure. This category includes lithium polymer batteries, which differ from traditional.
Titanate, silicon and silicides, as well as tin and tin alloys, are the new anode materials that have

been discussed in the context of research and development. All of these materials are regarded as offering improved safety as they do not form an SEI layer. The main advantage of titanate is that its structure is highly stable and there is no increase in volume during battery charging. Lithium's mobility within the material is very rapid, which permits the battery to be charged and discharged at high currents.

Many Li-Ion biochemistry are available. They are usually named according to the composition of the cathode. They include:

$LiCoO_2$: Standard lithium-cobalt-oxide;

LiMnNiCo: Lithium-manganese-nickel-cobalt;

$LiFePO_4$ and Li_2FePO_4F: Nano-phosphate/lithium-iron-phosphate/lithium ferro-phosphate;

$LiMnO_2$: Lithium-manganese-oxide;

$Li_4Ti_5O_{12}$: Lithium-titanate;

$LiMn_2O_4$: Lithium-manganese-oxide;

$LiNiO_2$: Lithium-nickel-oxide.

The nominal voltage, energy, and power density of these cells varies with their chemistry. Some are considered safer and are more appropriate for large traction packs (especially $LiFePO_4$ and lithium-titanate) compared to standard ($LiCoO_2$)Li-Ion cells.

Li-Ion cells are available in four basic formats: **cylindrical(small and large), prismatic, and pouch.** Some of these formats are far easier to use than others, making them more appropriate for small projects. Cylindrical cells inherently retain their shape against expansion due to chemical processes when fully charged, while, with the other formats, you must provide an overall battery enclosure to retain their expansion.

Trends in Lithium Ion Batteries

Trends that are noticeable within research & development of lithium ion batteries are:

1. A transition to cheaper and less toxic electrode materials (cathodes), e.g. phosphates and silicates.
2. The transition to materials that have higher reversible lithium reception. The more lithium atoms that the material can absorb in each unit cell, the higher will be the potential battery capacity.
3. Materials that can withstand rapid charges (from 0 to 90% SOC in ten minutes)
4. Power and energy batteries for the automotive industry and stationary installations.
5. Increased cell size in the form of stored energy capacity.
6. Battery systems with high voltage levels, including electrolytes that can withstand higher electrode potential without degrading or reacting with the environment.
7. Battery systems with enhanced safety compared to current battery types

BMS and PCM

Why we need PCM or Even BMS, let's first start with an example.
In a small battery with just a few cells in series, the charger voltage is divided nearly equally among the cells. For example , when charging a standard lead-acid starter battery for a car, a constant voltage of 13.5V is applied to it, and each of the six cells within it sees about 2.25V. If any cell is charged more, its voltage will be a bit higher, taking away some voltage from the other cells. For example, if one cell is at 2.5V, the other cells will be, on the average, at 2.20V. That delta voltage among cells is perfectly acceptable; lead acid cells are much more tolerant to variances in their voltage.
For another example, a small LiPo battery for a consumer product may have two cells in series. When charging with 8.4V, if the cells are balanced, each cell sees 4.2V. If the cells are out of balance, in the worst case the most discharged cell will be at 3.3V, leaving 4.9V on the most charged one. 4.9V is above the maximum rating for a LiPo cell (4.2V), but it is still low enough that it is not going to go in the thermal runaway and catch fire.
What if we are building a huge battery pack that contains more then 100 or even more cells?
In a high-voltage battery with many cells in series, though, there is a much greater chance that the overall pack voltage is not evenly divided among its cells.(This is true for any chemistry.)
Consider a four-cell LiPo battery, charged up to 16.8V. If the cells are perfectly balanced, the total voltage will be equally divided into 4.2V per cell .In practice, the cells will be unbalanced, and one will be the first to be fully charged and then be overcharged. It is therefore essential that a BMS monitor such a battery, first and foremost to prevent any cell from being overcharged, and optionally to balance the battery to maximize its performance.

Li-Ion BMSs

In the previous sections we saw how abusing Li-Ion cells may reduce their life, result in damage, and can even be a safety issue. Having analyzed the problems with Li-Ion cells, let us look at Li-Ion BMSs for solutions. It is the job of a BMS is to ensure that the cells in a battery are operated within their SOA. This is particularly important for large Li-Ion battery packs because:
1 Li-Ion cells are so much more unforgiving of abuse than other chemistries.
2 Large battery packs, with many cells in series, are more prone to be charged and discharged unevenly due to unbalance among cells. Li-Ion cells must not be overcharged or over-discharged.

Lithium-Ion Battery Design and Selection Considerations

The choice of battery in an application is usually driven by a number of considerations, including the application requirements for power and energy, the anticipated environment in which the battery-powered product will be used and battery cost.

Other considerations in choosing a suitable battery may include:

- Anticipated work cycle of the product (continual or intermittent)
- Battery life required by the application
- Battery’s physical characteristics (i.e., size, shape, weight, etc.)
- Maintenance and end-of-life considerations

Lithium-ion batteries are generally more expensive than alternative battery chemistries but they offer significant advantages, such as high energy, density levels and low weight-to-volume ratios.

Considerations on Custom Battery Pack

Glossary

It’s important to have a general idea of some common used terms, here are some of them:

A (amperage) output - this is the total current the battery pack will be able to provide. It measures the amount of electricity used. Amps multiplied by volts is equal to wattage.

mAh (milliamp hour) output - this is the total capacity of your battery measured in milliamp hours, which are a 1000th of an amp hour (Ah). Either measure can be used. The higher the mAh, the longer your battery will last before it needs to be recharged.

V (Voltage) output - Volts are a measure of electric potential energy and represent the amount of energy that could be released if current is allowed to flow.

W (watt) output - Watts are another measure of electric power; watts depends on amps and volts (watts are equal to Volts multiplied by amps). The watt unit is defined as joule per second.

AH(Ampere-Hour) -- One ampere-hour is equal to a current of one ampere flowing for one hour. A unit-quantity of electricity used as a measure of the amount of electrical charge that may be obtained from a storage battery before it requires recharging.

Special requirements - Do you need a special box to prevent corrosion from salt spray? Or temperature control in very cold or hot environment? What is special about your project and the battery’s environment that will add additional systems to the custom batteries?

2 *How to design a battery pack*

Purpose of battery packs

Battery cells come in fixed voltages and capacities. Capacities do vary, but voltages don't, In order to meet your power requirements a battery pack may need to be used. The types of battery, the number of cells, the shape of the pack, and the components of the pack will be determined by the voltage and load current of the device being powered.
Other considerations will be available space, operating temperature, usage conditions, transportation requirements, and charge/discharge specifications.

Configurations

Pls ignore the configuration part if you are not engineer, this is for the design and size purpose.

Configuration - The configuration of the battery pack includes both the cell count and how they are arranged either in a series or in parallel, or in a combination of both configurations.
General types:
Serial - Increases voltage
Parallel - Increases capacity
Serial / Parallel - A combination of both

Common battery pack configuration formats:

B Format - end to end
C Format - side by side
BC Format - a combination of B and C formats
Standard - Side by side interlinked with solder tags
Cluster Format - Polygon shape interlinked with solder tags
Nest Format - Staggered interlinked with solder tags

Custom battery pack configurations describe how individual cells are connected together to create a complete battery pack. The environment in which the battery pack is used and the electrical connection of the individual cells (series or parallel) are two key considerations when designing a battery pack and working out the best configuration. The increasing need for more power in smaller spaces and the wide variety of our customers' applications mean we have designed and made a large number of different battery pack configurations.

Connectors

Many of the custom battery packs we build have flying leads and connectors. Battery pack connectors are usually specified by our customer to ensure the battery pack is attached correctly to the device with the right polarity. Fitting a connector also helps to prevent the possibility of the positive and negative terminals touching creating a short circuit, which will damage the battery pack.

There are literally thousands of battery pack connectors but we can usually identify the correct connector for customer applications with the use of digital images and specifications (including wire polarity). We tend to hold a good stock of common connectors and assemblies in our warehouse and we have excellent relationships with connector and component suppliers enabling a quick turnaround for our customers.




PCM/BMS (battery management system)

There is no unique definition of what a BMS is and does, and sometimes other terms [such as voltage management system (VMS) or protection circuit module (PCM)] are used for what is in effect a BMS. Here I take the wide view that a BMS is any product or technology used with the intent of taking care of a battery in one way or another. This may include any of the following functions:

To monitor the battery;

To protect the battery;

To estimate the battery's state;

To maximize the battery's performance;

To report to users and/or external devices.

Li-Ion BMS Functions

* For the sake of safety, and for the sake of the cells, a Li-Ion BMS must, at the very least (in order

of importance), do the following:

* Prevent the voltage of any cell from exceeding a limit, by stopping the charging current, or requesting that it be stopped. This is a safety issue for all Li-Ion cells.

* Prevent the temperature of any cell from exceeding a limit by stopping the battery current directly, requesting that it be stopped, or requesting cooling. This is a safety issue for Li-Ion cells that are prone to thermal runaway.

* Prevent the voltage of any cell from dropping below a limit by stopping the charging current or requesting that it be stopped.

* Prevent the charging current from exceeding a limit (which varies with cell voltage, cell temperature, and previous level of current) by requesting that the current be reduced or stopped, or by stopping the current directly.

* Prevent the discharging current from exceeding a limit, as described in the previous point.

A BMS is essential when charging a Li-Ion battery. As soon as any cell reaches its maximum charged voltage, it must turn off the charger . A BMS may also balance the battery to maximize its capacity. It may do so by removing charge from the most charged cell until its voltage is low enough that the charger may come back on and give the other cells a change to be charged. After many cycles of this process, all the cells will be at the same voltage, fully charged, meaning that the pack will be balanced. A BMS is also essential when discharging a Li-Ion battery. As soon as any cell reaches a low cutoff voltage, it turns off the load

Heat Shrink Tubing

The most common way to hold the pack together is to use heat shrink tubing. Heat shrink tubing is typically made of PVC and varies in thickness based upon battery type and configuration.

Protective Cases

The most typical type of protective cases are injected molded plastic or steel cases. These can be custom designed for every application.

Charger Selection

You can depend on us to get chargers for you or you can source at your side.

If in any case you still don't know how to design the battery pack, please do send an inquiry to us, we are here to help with your projects, simple drop an email to sales@dnkpower.com

3 *Some other aspect you need to know about battery*

In the following part, we will introduce you with other aspect that you need to consider while select the battery.

Risks and Safety Factors for Lithium Batteries

While high energy density is noted as a benefit of lithium batteries, high energy content, is responsible for safety risks associated with lithium-based chemistry, in comparison to other battery systems. Although the risks are directly linked to the specific cell chemistry, cell size and the number of cells in the battery, there are certain common factors. Lithium batteries contain flammable material in the form of organic electrolytes that have a low flash point and polymers that can maintain a fire and increase the risk of spreading to surrounding areas. The anode in primary lithium batteries consists of metallic lithium that melts at 180°C. Both lithium metal and charged Li-ion anodes react violently with water, generating highly flammable hydrogen gas.
Low temperatures can also pose a problem. Rechargeable batteries often have limited changeability at low temperatures, and should not be charged if the ambient temperature is lower than the lowest recommended charge temperature, as it may lead to formation of metallic lithium (i.e. lithium plating). Lithium is known to form dendrites when plated, and these can result in internal cell short circuits if the dendrites pierce the separator barrier membrane.

External Causes of Battery Failure

Chances of battery failures are the result of conditions which generate heat within the battery cell, and lead to increased aging or breakdown of the cell. As these risks are caused by external factors, it is possible to prevent and avoid them.

External short circuit

When battery poles are short circuited, the short circuit current can generate heat in the cell. The most efficient way of preventing this from happening is to employ smart battery design to ensure the positive and negative poles are physically isolated from each. This can be achieved by countersinking them into the battery casing and designing them in such a way that it is not possible to connect the battery incorrectly. In certain cases, it may be necessary to integrate further protection in the form of a fuse or a PTC (Positive Temperature Coefficient) component, which breaks the electrical circuit if the current or the temperature begins to run away. Certain cell manufacturers integrate PTC components in their cells. These components are commonly integrated into the caps of cylindrical sized cells, such as the 18650.

High discharge or charge current

If the current is too high, the mass transport of the reactants for the main reactions is limiting, and the energy supplied is partially consumed by side reactions in the cell, such as gassing and decomposition, which lead to increases in temperature. If the temperature is too high, it may lead to further side reactions which in turn generate even more heat. This increases the risk of venting and, in the worst-case scenario, uncontrolled cell reactions and thermal runaway.
When charging secondary cells, it is important not to exceed the recommended maximum charge current. If the charge current is too high, there is a risk that the lithium-ions will not properly

diffuse into the anode structure during charge, but rather precipitate as lithium metal on the anode surface. This not only results in loss of cell capacity but increases the risk of internal short circuits during subsequent use.

Protection Capability Test Method and Request

Overcharge Test

Test Method: Apply a 5V voltage and a 1C charge current on the battery for 10 hours.

Request: Battery could not be burst, burn, leak and smoke

Over discharge Test

Test Method: Discharge the battery at 1C to cut off voltage then discharge with loading 30Ω for 24hs.

Request: Battery could not be burst, burn, leak and smoke

Over-current Protection Test

Test Method:1) The battery is fully charged to rated capacity.

2) Load current at 0.2A/S to cut off the output of the battery.

Request: Battery could not be burst, burn, leak and smoke

Short-circuit Protection Test

Test Method:

1) The battery is charged to rated capacity.

2) The battery is to be short-circuited by connecting the positive and negative terminals of the battery with Thermos couple having a maximum resistance load of 0.1Ω for 1h.

Request:

Battery could not be burst, burn, leak and smoke After charging.

After charging the battery can be used normally.

Applicable Product Safety Standards and Testing Protocols

International Electro technical Commission

• IEC 62133: Secondary Cells and Batteries Containing Alkaline or Other Non-acid Electrolytes — Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from Them, for Use in Portable Applications

• IEC 62281: Safety of Primary and Secondary Lithium Cells and Batteries

During Transportation

United Nations (UN)

• Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, Part III, Section 38.3

Japanese Standards Association

• JIS C8714: Safety Tests for Portable Lithium-Ion Secondary Cells and Batteries

For Use In Portable Electronic Applications

Battery Safety Organization

• BATSO 01: (Proposed) Manual for Evaluation of Energy Systems for Light Electric Vehicle (LEV) — Secondary Lithium Batteries

Electrical Tests

• External Short Circuit Test— The external short circuit test creates a direct connection between the anode and cathode terminals of a cell to determine its ability to withstand a maximum current flow condition without causing an explosion or fire.

• Abnormal Charging Test— The abnormal charging test applies an over-charging current rate and charging time to determine whether a sample cell can withstand the condition without causing an explosion or fire.

• Forced Discharge Test— The forced discharge test determines a battery’s behavior when a discharged cell is connected in series with a specified number of charged cells of the same type. The goal is to create an imbalanced series connected pack, which is then short-circuited. To pass this test, no cell may explode or catch fire.

Mechanical Tests

• Crush Test— The crush test determines a cell’s ability to withstand a specified crushing force (typically 12 kN) applied by two flat plates (typically although some crush methods such as SAE J2464 include a steel rod crush for cells and ribbed platen for batteries). To pass this test, a cell may not explode or ignite. (This test is not required under IEC 62281 or UN 38.3).

• Impact Test— The impact test determines a cell’s ability to withstand a specified impact applied to a cylindrical steel rod placed across the cell under test. To pass this test, a cell may not explode or ignite. (This test is not required under SAE J2464, JIS C8714, or BATSO 01).

• Shock Test— The shock test is conducted by securing a cell under test to a testing machine that has been calibrated to apply a specified average and peak acceleration for the specified duration of the test.

To pass this test, a cell may not explode, ignite, leak or vent.

• Vibration Test— The vibration test applies a simple harmonic motion at specified amplitude, with variable frequency and time to each cell sample. To pass this test, the cell may not explode, ignite, leak or vent

Environmental Tests

• Heating Test— The heating test evaluates a cell’s ability to withstand a specified application of an elevated temperature for a period of time. To pass this test, the cell may not explode or ignite. (This test is not required under IEC 62281, UN 38.3 or BATSO 01).

• Temperature Cycling Test— The temperature cycling test subjects each cell sample to specified temperature ranges above and below room temperature for a specified number of cycles. To pass this test, the cell may not explode, ignite, vent or leak.

• Low Pressure (altitude) Test— The low-pressure test evaluates a cell sample for its ability to withstand exposure to less than standard atmospheric pressure (such that in an aircraft cabin that experiences sudden loss of pressure). To pass this test, the cell may not explode, ignite, vent or leak.