Lithium-ion Batteries

Lithium-ion batteries are very popular these days. They are common in consumer electronics such as laptops, PDAs, cell phones and iPods and most of the latest gadgets with one of the best energy densities, no memory effect and only a slow loss of charge when not in use. They are so common because, pound for pound, they're some of the most energetic rechargeable batteries available.

Lithium-ion batteries have also been in the news lately. That’s because these batteries have the ability to burst into flames occasionally. It's not very common -- just two or three battery packs per million have a problem -- but when it happens, it's extreme. In some situations, the failure rate can rise, and when that happens you could end up with a worldwide battery recall that can cost manufacturers millions of dollars. For example; in 2013 a Japan Airlines Boeing 787 lithium cobalt oxide battery caught fire. This caused major problems for the airline, having to spend hundreds of hours testing all of the batteries on the airplane itself to determine what actually cause the battery to catch fire, all at a great financial loss to the company.

So the real question is: what makes these batteries so energetic and so popular? How do they burst into flame? And is there anything you can do to prevent the problem or help your batteries last longer?

Lithium-ion batteries are popular because they have a number of important advantages over competing technologies:

- They're generally much lighter than other types of rechargeable batteries of the same size. The electrodes of a lithium-ion battery are made of lightweight **lithium** and **carbon**. Lithium is also a highly reactive element, meaning that a lot of energy can be stored in its atomic bonds. This translates into a very high **energy density** for lithium-ion batteries. Here is a way to get a perspective on the energy density. A typical lithium-ion battery can store 150 watt-hours of electricity in 1 kilogram of battery. A **NiMH (nickel-metal hydride) battery** pack can store perhaps 100 watt-hours per kilogram, although 60 to 70 watt-hours might be more typical. A **lead-acid battery** can store only 25 watt-hours per kilogram. Using lead-acid technology, it takes 6 kilograms to store the same amount of energy that a 1 kilogram lithium-ion battery can handle. That's a huge difference!
- They definitely hold their charge! A lithium-ion battery pack loses only about 5 percent of its charge per month, compared to a 20 percent loss per month for NiMH batteries.
- They have no **memory effect**, which means that you do not have to completely discharge them before recharging, as with some other batteries.
- Lithium-ion batteries can handle hundreds of charge/discharge cycles. Whereas other batteries don’t come close to them.

But that is not to say that lithium-ion batteries are flawless. They have a few disadvantages as well:

- They start degrading as soon as they leave the factory. They will only last (on average) two or three years from the date of manufacture whether you use them or not. Usage and device applications also come into play. For example: A cell phone battery might average less because of the type of software that manufactures uses or the general use of the battery in general. If you are using lots of apps, or use it for gaming purposes that may shorten the 'expected' life of the battery itself.
- They are extremely sensitive to high temperatures. Heat causes lithium-ion battery packs to degrade much faster than they normally would (this would also apply to most other types of batteries too). So if you live in a region where you're always experiencing fantastic hot weather, your battery might not live as long as someone who lives in the cooler climates. If you live in Calgary, that could be hit or miss, especially with our climate.
- If you completely discharge a lithium-ion battery, it is ruined. Which is why it's always good to give a lithium-ion battery a good 8-12 hour charge prior to initial use, don't let a new lithium battery die prior to that charge. Otherwise you may have wasted your money.
- A lithium-ion battery pack must have an on-board computer to manage the battery. This can make them even more expensive than they already are. So in an application of a cell phone, your cell phone itself monitors that. In cases of individual cells, or in combination pack, most of the circuitry boards are included with that pack (most of them underneath the shrink packaging). Or in some cases, that circuitry board is already built into that application, it's just missing the battery to operate it
- There is a small chance that, if a lithium-ion battery pack fails, it will burst into flame. Even though it is a small chance, the underlying principal is that it still can happen. Over charging that lithium-ion pack can cause it to burst into flames as well. There can be multiple ways that a lithium-ion pack could cause a malfunction and catch fire. As with all batteries, they are meant to be taken care off, so if you take care of them your chances are much lower.
- Charging forms deposits inside the electrolyte that inhibit ion transport. Over time, the cells capacity diminishes (as with all batteries). The increase in internal resistance reduces the cell's ability to deliver current. This problem is more pronounced in high-current applications. The decrease means that older batteries do not charge as much as new ones.

Inside a Lithium-ion Battery Pack and Cell

Lithium-ion battery packs come in all shapes and sizes, but they all look about the same on the inside. If you were to take apart a laptop battery pack (something that we **STRONGLY DO NOT RECOMMEND** because of the possibility of shorting out a battery and starting a fire or causing major injuries to your body/face) you would find the following:

- The **lithium-ion cells** can be either cylindrical batteries that look almost identical to AA cells, or they can be **prismatic**, which means they are square or rectangular The computer, which comprises:

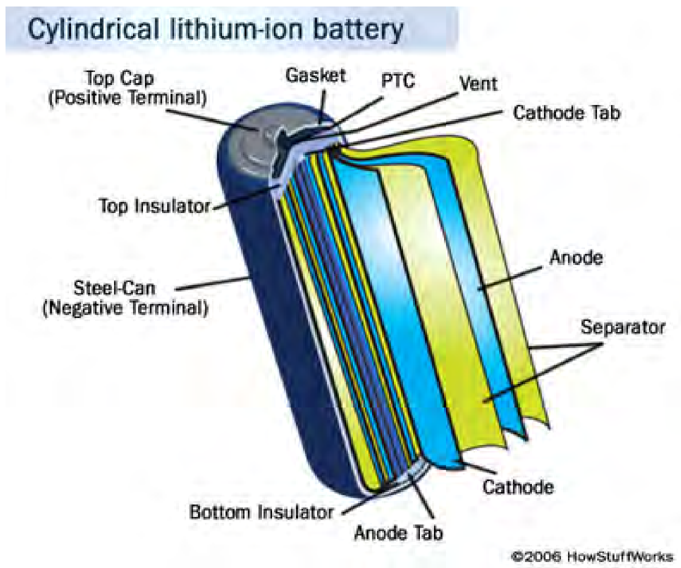
- One or more **temperature sensors** to monitor the battery temperature
- A **voltage converter and regulator circuit** to maintain safe levels of voltage and current
- A shielded **notebook connector** that lets power and information flow in and out of the battery pack
- A **voltage tap**, which monitors the energy capacity of individual cells in the battery pack
- A **battery charge state monitor**, which is a small computer that handles the whole charging process to make sure the batteries charge as quickly and fully as possible. So in most cases, should your battery run out of capacity, or should you have other issues with it, it is always best to purchase another battery. Most commonly it's the circuitry board and the other functions of that battery pack that have malfunctioned and not necessarily the batteries themselves. But the possibility that it is actually the batteries is still there.
- To reduce this risk, Li-ion batteries contain fail-safe circuitry that shuts down the battery when its voltage is outside the safe range of 3-4.2 V per cell.
- When stored for long periods the small current draw of the protection circuitry itself may drain the battery below shut down voltage; normal chargers then become ineffective. Many types of lithium-ion cells cannot be charged safely below 0 degrees Celsius. But on the plus side, operate well at lower temperatures. So outside applications such as weather meters or garden lamps will still work at colder temperatures, but should be brought into the house, and brought to room temperature to be charged properly.
- Some other safety features are required in each cell: **Shut down separator** (for over temperature), **Tear-away tab** (for internal pressure), **Vent** (pressure relief) and **Thermal interrupt** (overcurrent/overcharging)
- These devices occupy useful space inside the cells, adding points of failure and irreversibly disable the cell when activated. They are required because the anode produces heat during use, while the cathode may produce oxygen. These devices and improved electrode designs reduce/eliminate the risk of fire or explosion. Further, these features increase costs compared to nickel metal hydride batteries, which require only a hydrogen/oxygen recombination device (preventing damage due to mild overcharging) and a back-up pressure valve.
- If overheated or overcharged, Li-ion batteries may suffer thermal runaway and cell rupture. In extreme cases, this can lead to combustion. Deep discharge may short-circuit the cell, in which case recharging would be unsafe

If the battery pack gets too hot during charging or use, the computer will shut down the flow of power to try to cool things down. If you leave your laptop in an extremely hot car and try to use the laptop, this computer may prevent you from powering up until things cool off. Just like an apple iPhone, if you leave it in the sun for too long, a warning will pop up telling you to cool off the phone prior to use. It won't even let you open up the phone until it has cooled down to operating temperatures. If the cells ever become completely discharged, the battery pack will shut down because the cells are ruined. It may also keep track of the number of charge/discharge cycles and send out information so the laptop's battery meter can tell you how much charge is left in the battery.

It's a pretty sophisticated little computer, and it draws power from the batteries. This power draw is one reason why lithium-ion batteries lose 5 percent of their power every month when sitting idle.

<u>Lithium-ion Cells</u>

As with most batteries you have an outer case made of metal. The use of metal is particularly important here because the battery is pressurized. This metal case has some kind of pressure-sensitive **vent hole**. If the battery ever gets so hot that it risks exploding from over-pressure, this vent will release the extra pressure. The battery will probably be useless afterwards, so this is something to avoid. The vent is strictly there as a safety measure. So is the **Positive Temperature Coefficient (PTC)** switch, a device that is supposed to keep the battery from overheating.



This metal case holds a long spiral comprising three thin sheets pressed together:

- A **Positive electrode**
- A **Negative electrode**
- A **separator**

Inside the case these sheets are submerged in an organic solvent that acts as the electrolyte. Ether is one common solvent.

The separator is a very thin sheet of micro-perforated plastic. As the name implies, it separates the positive and negative electrodes while allowing ions to pass through.

The positive electrode is made of Lithium cobalt oxide, or $LiCoO_2$. The negative electrode is made of carbon. When the battery charges, ions of lithium move through the electrolyte from the positive electrode to the negative electrode and attach to the carbon. During discharge, the lithium ions move back to the $LiCoO_2$ from the carbon.