LITHIUM RECHARGEABLE BATTERIES: SAFETY INFORMATION

Lithium batteries have revolutionized consumer electronics by allowing a large amount of energy to be stored in a compact and lightweight package. However, their construction and chemical composition is completely different from earlier battery types, and they can be extremely dangerous if mistreated.

With care in construction of the batteries and the use of the correct type of charging system, the danger is minimized. It is when manufacturers take shortcuts with the design that trouble can occur.

CHEMICAL DIFFERENCES.

Virtually all other battery types in common use contain water-based liquids (generally known as "electrolytes"). They can contain sulphuric acid (as used in car batteries), potassium hydroxide (similar to caustic soda and used in alkaline and Nickel-Cadmium batteries) or Ammonium Chloride, a much less corrosive substance used in paste form in common carbon-zinc cells.

Lithium cells on the other hand use an organic solvent which smells similar to the acetone used in nail polish, and is just as inflammable. *This is the major difference between Lithium cells and all other types*: Water-based electrolytes don't burn, because, they're … well, mostly *water….*

The organic solvents used in lithium batteries on the other hand are not just highly inflammable, they're also extremely volatile. You may have seen YouTube videos where people have deliberately caused lithium batteries to ignite, such as the example shown here.

In this case the explosion was caused by bypassing all the safety mechanisms and deliberately over-charging the battery. Also, this was a very poorly-designed battery, with basically a flimsy aluminium bag holding the entire battery assembly and electrolyte. Over-charging first causes the solvent to boil, bursting the battery package, and then internal sparking ignites the solvent vapour. While this particular explosion was deliberately engineered, *the same thing can happen without warning if either the battery is poor quality, or the charger is poorly designed.*

CORRECT CHARGER DESIGN PRACTICE.

The charging cycle of Lithium-Ion cells (the most common type) is broadly similar to that of lead-acid cells. With lead-acid, each cell requires a constant voltage of 2.3V applied to charge correctly. With 2.3V applied, the cell will automatically take the exact amount of current required to fully charge it, and when it reaches

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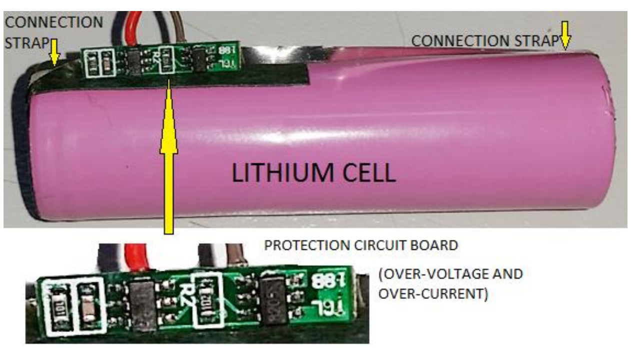
full charge, the charge current will drop to zero. This is known as the “float voltage”

(Single lead-acid cells are not used all that often; it is more common to use a “battery” of such cells wired to give a higher voltage, the most common being a battery of 6 cells, giving a nominal and more familiar “12 Volt battery”. A 12V battery has a float voltage of 2.3 x 6 = 13.8V).

Lithium cells deliver a considerably higher voltage, around 3.7V per cell, so in a lot of cases it is practical to power products from a single lithium cell. The most common example is probably the mobile phone, but most modern cameras and many portable entertainment devices also use a single cell.

The most common float voltage for a single lithium-Ion cell is 4.2 Volts, (some less-common types require 4.1 Volts). However, lithium cells are far trickier to safely charge than lead-acid, and rather than just a charger, they need a complete battery “management” system involving a lot of complex electronics. *It’s where manufacturers take shortcuts with the design that dangerous situations can develop.*

Ideally, the lithium cell itself will carry come sort of on-board overload protection, usually on a miniature circuit board as shown here:

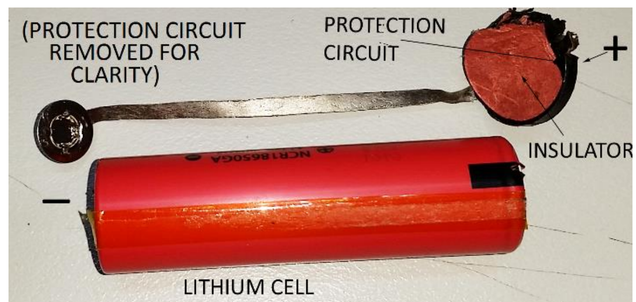


That is a lithium cell from a portable music player. It is a standard 18650 type (18mm x 65mm), except that instead of taking power directly from the end caps in the usual manner, thin metal connecting straps are spot-welded to the ends, and the charge and discharge currents are routed through the circuit board. This circuit will automatically disconnect the cell if any of these three events occurs:

• Excessive charge current
• Excessive discharge current
• Excessive charge voltage

(That particular cell also has a basic temperature monitoring function, which requires the sensor chips to be in direct contact with the cell, but not all systems have this).

Other designs have the protection circuitry built into a coin-shaped module fitted on one end as shown here. The black disc contains the protection circuitry, and the connecting strip



allows the circuit to monitor the battery voltage. This allows the cells to be removed and replaced like ordinary non-rechargeable cells. (The above example has had the outer wrapping removed to show the interior circuitry; normally it looks very similar to a standard 18650 cell).

Below is a diagram of a typical setup. Ideally there should be a “Polyswitch” type self-resetting fuse directly in series with the cell in case the protection module develops a fault, but not all designs have these. The entire structure in the

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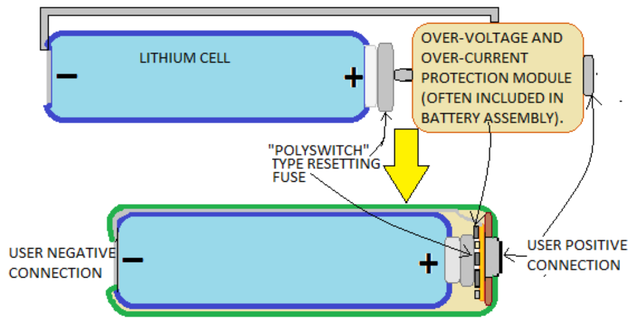
top image is usually then wrapped in another layer of heat-shrinkable plastic, shown in green. What is often not understood by manufacturers is that the circuitry shown above is only intended as a *backup* if the main battery management

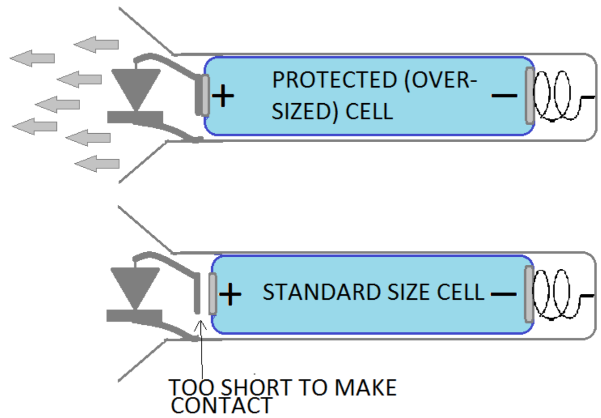


system fails. Far too many manufacturers depend on what is only intended as a safety backup to actually regulate the charging, using just a simple plugpack power supply.

In some cases, the provided plugpack actually produces a regulated 4.2 Volts which will correctly charge the battery *if* it is working correctly. If the backup board is fitted that will give a reasonable level of protection in case either the regulator fails, or (more likely) someone plugs in the wrong voltage plugpack.

However, this all falls apart if the user replaces the original protected battery with a non-protected type. To prevent this, many torches and similar devices use a protected cell that is about 5mm longer than the standard 18650. That way, if somebody substitutes a non-protected 18650 cell, it can't make electrical contact, so it can't be over-charged.

Unfortunately, other torch manufacturers use protected cells that *are* the standard 18650 size, and fitting a non-protected cell can result in explosion or fire, depending on what sort of charger is used.



Again, too many manufacturers take shortcuts with the charger design, basically connecting a much higher voltage plugpack direct across the cell(s) and depending on the safety protection circuitry to terminate the charge when the battery is full.

This is barely satisfactory when the proper type of battery is used, and can result in explosion or fire if it is not.

Remember: The on-board protection system is ONLY intended as a safety backup; it is NOT intended to be used as the main charge controller! Such a setup will fail most countries' safety standards.

SOME COMMON EXAMPLES OF POORLY DESIGNED LITHIUM CHARGING SYSTEMS:

Straight 5-12V plugpack, with a current limiting resistor (if you're lucky).

Issue:

If you replace the protected cell with a non-protected type, it may over-charge and possibly explode.

4.3 Volt regulated plugpack (that is, power supply, not proper charger)

Issue:

Better than the above and can be OK even with non-protected cells. *As long as* nobody plugs in the wrong charger….

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Better, More Technical

5.0 Volt plugpack that depends upon silicon diode inside appliance to drop voltage to about 4.3 Volts.
Issue:
Pretty much same as above.
Mini or micro USB-type charging socket.
Issue:
Again, similar to above, *except:*

1. The "Legal" USB voltage range is actually 4.75V to 5.25V, leading to under- or over-charging.
2. Many devices intended for car use (eg dashcams, SatNav) come with "Illegal" cigarette lighter-to-USB adaptors, which deliver the full 12-14 Volts to the USB socket, (ie wired "straight through"). The original devices they came with may be OK with either 5V or 12V; a battery charging system that's expecting 5.0 Volts will definitely *not* be! The same thing often happens to mobile phones: "Oh look; I can just charge my phone with the DashCam lead! What's all that smoke…?"

SO, WHY DON'T ALL LITHIUM CELLS HAVE BUILT-IN PROTECTION?

Built-in protection is fine if you know in advance what the expected current drain and charge currents are going to be. But the harder the battery is "hammered" in normal use, the more complex the safety protection needs to be. A common example is lithium battery power tools. These can draw very large currents in operation and require fast recharge times. This can still be achieved safely, but *only* by tightly monitoring the condition of the battery at all times, which requires complex circuitry (see later),

In the case of something like a torch or portable sound device, the expected current drain is much more predictable and the protection circuitry can be tailored to suit. Because it's usually fairly low, a relatively simple charger and protection system is good enough.

For lithium cells sold as general-purpose replacements, such as the Jaycar SB2308, it is not practical to have on-board over-current protection, as the manufacturer has no way of knowing what type of service the cell is going to be subjected to. For example, if the SB2308 is going to be used in something like a large radio-controlled toy car or helicopter, having a protection system designed for a torch would mean it would neither be able to deliver the peak currents demanded, nor allow a rapid enough recharge time.

EXAMPLE OF CORRECT DESIGN PRACTICE.

When rechargeable lithium batteries first became available in the early 1990s, they were very expensive, and mainly used in professional video cameras and similar high-end applications. Part of the reason for the high cost was the sheer amount of electronics required to maintain safe operation, which had to be mostly assembled from off-the-shelf chips and discrete components.

The development of custom control chips has greatly reduced this cost overhead, and at first glance it may not be at all obvious how complex the battery pack needs to be.

On the next page is an example of a correctly-designed lithium battery management system, such as might be found in power tools and similar high-drain devices.

Note that this is only a 3 cell-battery, supplying about 12 Volts; electric vehicle batteries and similar can consist of hundreds of cells, making the management circuitry staggeringly complex.

(Also, most metal Nickel hydride and NiCad fast chargers operate on roughly similar principles to what is shown, with much the same setup for switching the cells in and out of circuit).

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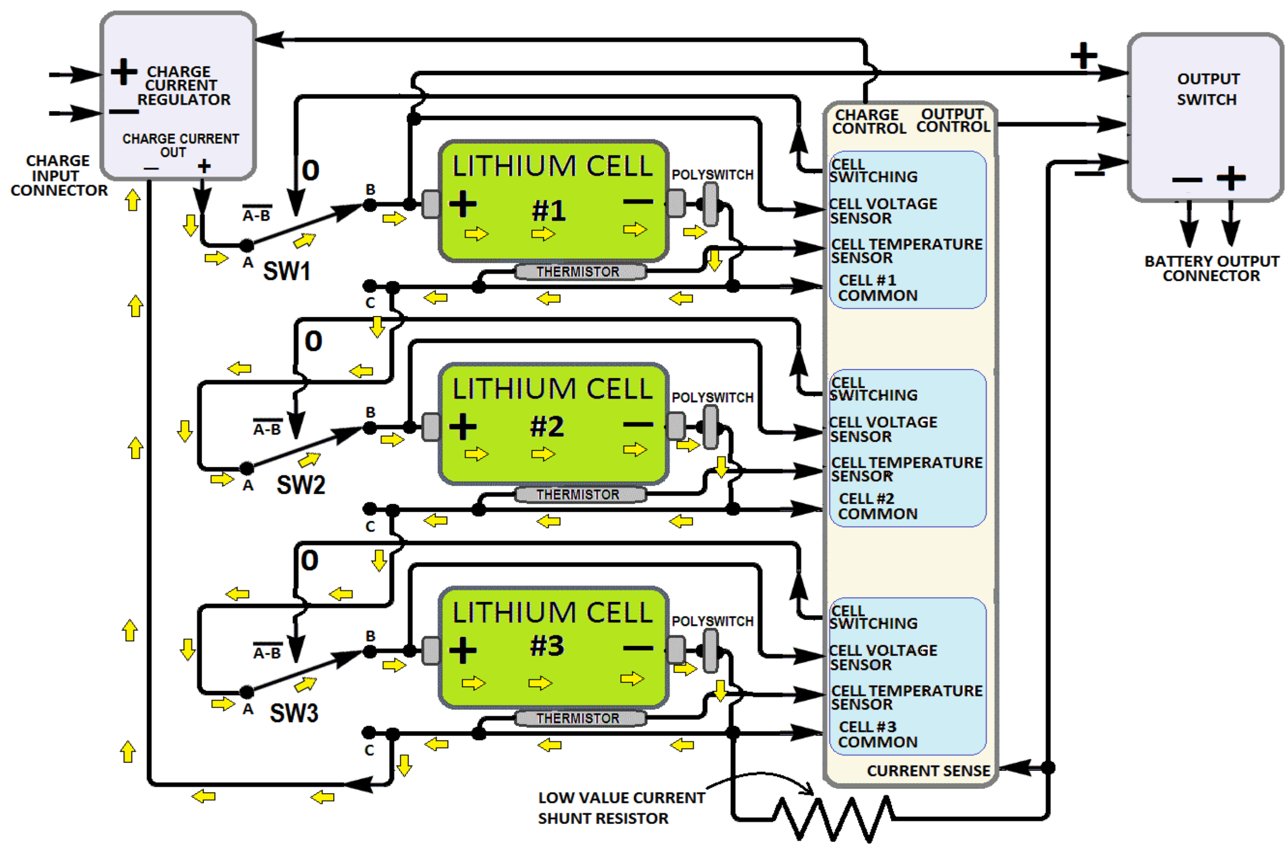
The particular pack illustrated here has a separate charge input socket, which is more common with medium-to-high power devices where the battery is detached and plugged into a separate charger.

SW1, SW2 and SW3 behave like changeover relays, but they are normally fabricated from an assembly of N-Channel and P-Channel power MOSFETS. In smaller devices these are incorporated into an IC, while larger devices may use discrete devices controlled by a specialized IC. In this case, Taking the control pin low makes the connection between points A and B.

The three lithium cells each have individual connections to the control chip to monitor the cell's voltage, plus a thermistor pressing against the cell to measure the temperature.
The charge current regulator is normally a switchmode current source, also driven by the controller chip.

During charging, the three cells are initially connected in series via SW1, SW2 & SW3, the charge current following the path depicted by the arrows.

During discharge, the current is routed through SW2, SW3, and a similar device in the output switching assembly. At all times the cells are intensively monitored, and charging or discharging can be terminated instantly if any undesirable situation occurs.



FULL CHARGE MODE
ALL 3 CELLS CONNECTED TO CHARGE CIRCUIT

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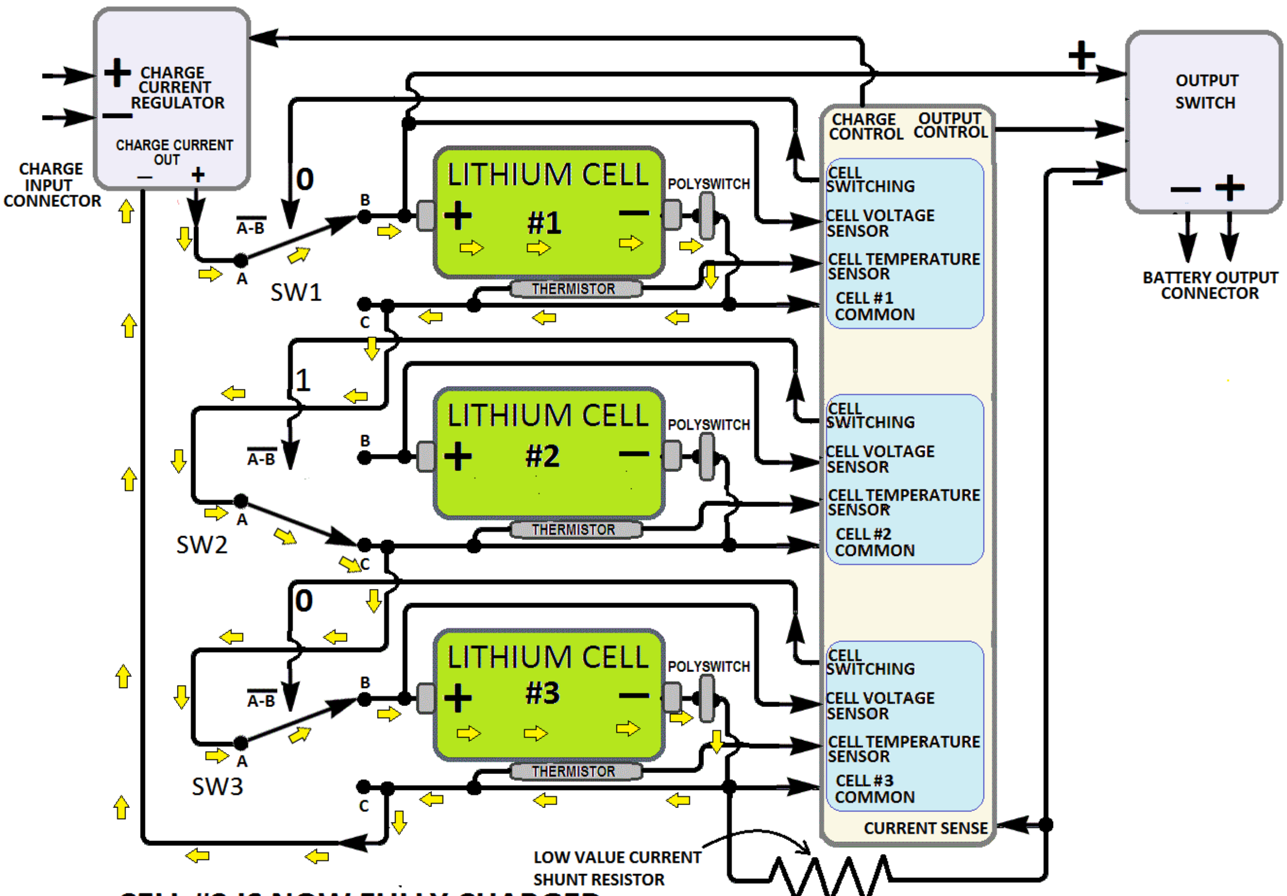
As an example, the next diagram shows what happens when cell #2 either reaches its maximum safe charge voltage, or its temperature rises excessively. The controller chip senses the undesirable condition and immediately switches SW2 A to C, bypassing Cell #2. Charging will then continue until either Cell #1 or Cell #3 reaches maximum voltage or overheats, and SW1 or SW3 activates.

Tight control is also required over discharging, both to avoid dangerous short-circuits and cell overheating, and also to ensure that none of the cells drops below 3.0 Volts. (A lithium cell can easily be ruined by over-discharge). The instant the controller detects that any of the cells has fallen below that voltage, the output switch immediately disconnects the battery assembly from the output socket.

An on-board low-value shunt resistor in the negative battery line allows the controller chip to monitor the current being drawn from the battery and make decisions about whether the battery is being overloaded. The great advantage of this system is that the microcontroller can be programmed to ignore short-term current surges that occur during the operation of the appliance.

Finally, a “polyswitch” type self-resetting fuse should be placed in series with each cell, in case a short-circuit develops in the control electronics.



CELL #2 IS NOW FULLY CHARGED
SW2 HAS SWITCHED IT OUT OF CIRCUIT

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