Gibbs Guides

Lithium Polymer Batteries

A modeller's guide to
Lithium **Po**lymer (LiPo)
batteries.

A Gibbs Guides e-book

Andrew Gibbs

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A message from Andrew Gibbs

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Andrew Gibbs

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Welcome

Over recent years lithium polymer (also known as LiPo, Li-Po or Li-Poly) batteries have become the most common battery choice for electric powered model aircraft. Their light weight, high voltage and high power density are the prime reasons for this. These advantages have strongly contributed to making high performance electric model aircraft an everyday reality.

Early lithium cells were of Lithium Polymer and Lithium Ion varieties. Although light in weight, they could not be said to be high performance energy sources since both chemistries were limited to relatively low current values. It was also well recognised early on that lithium cells suffered from an unfortunate tendency to catch fire if they were not treated correctly.

Since those early days, lithium technology has now matured into a more reliable high performance source of energy. Much has changed ~ the LiPo variety has come to totally dominate the battery market, the quality of cells has risen and many improvements have been implemented to address safety concerns. Most notably, the fitting of balancing connectors to LiPo packs has become standard, balancing while charging has become the norm and new equipment has become available to assist with the safe operation of lithium batteries.

However, given the right (or should I say wrong) circumstances fire is still a possibility, so one thing that’s not changed is the need for vigilance concerning safety matters. Because of this factor in particular, there’s still a demand for a clear and practical guide to using LiPo batteries aimed specifically at the needs of modellers.

This new Gibbs Guide concentrates only on LiPo batteries. It incorporates the experience of more than 30 years of experience of using rechargeable batteries for modelling purposes combined with considerable LiPo experience plus detailed research. The material has also been discussed at length with leading suppliers of LiPo cells, as well as a number of the most experienced experts in electric modelling.

My intention has been for this guide to be technically informative, yet remain easily digestible for modellers. I hope I’ve succeeded, and I hope that you will find the guide an excellent companion to assist you in your work with LiPo batteries.

Andrew Gibbs

Acknowledgements
Grateful thanks are extended to everyone who helped make this guide a reality. In particular, I’d like to acknowledge the valuable contributions made by Toni Reynaud for his patience and most excellent charts as well as George Worley of 4-Max.co.uk, for both proof reading and for sharing his technical expertise. Thanks also to Andy Kirby at FlightTech for final proof reading.

DISCLAIMER

The instructions supplied with your LiPo batteries and associated equipment such as chargers, balancers etc must be accurately followed without deviation. None of the information within this guide is intended to overrule such instructions. Where any disagreement exists, always follow the instructions of the manufacturer and contact them or the supplier of your equipment for advice about the particular circumstances of your application.

All possible care has been taken with this guide and the information within it is offered in good faith; nevertheless, in using this guide you do so at your own risk and absolve the author of any liability whatsoever in respect of death, personal injury, damage to property or any other kind of accident. By purchasing this guide, you have already indicated that you accept these terms.

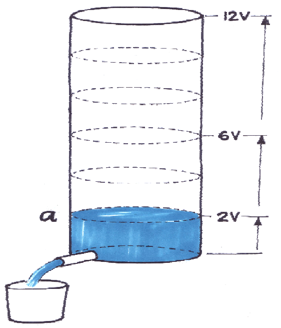
Chapter 1: Battery Basics

What is a battery?
A battery is simply a 'chemical machine' for storing electrical energy. The term *battery* is generally taken to mean two or more individual electric *cells.* There are two basic types of cell; primary and secondary. Primary cells, such as ordinary 'dry' cells, are not rechargeable and must be discarded when exhausted. Secondary cells, such as the Lithium-Polymer type are rechargeable.

The most familiar form of secondary battery is probably the standard 12V lead-acid car battery. This takes the form of a plastic tub, sub-divided into 6 individual compartments or cells, each cell producing 2V. Within each cell a number of lead plates are suspended in an electrically conductive fluid, called an *electrolyte*, which in this case is diluted sulphuric acid. A chemical reaction between the metal (lead) and the electrolyte (acid) generates a voltage. The voltage generated depends on the particular combination of the materials chosen. Lithium cells share this same basic design concept, where the metal lithium is placed in contact with a polymer electrolyte to create a voltage.

A brief explanation of electricity.
Many of us find the principles of electricity something of a mystery. Fortunately, those used in a modelling context are quite simple to learn, so let's first recap on a few electrical terms. As you progress through this guide, you may find it useful to refer back to this section as the need arises. To help explain these terms, we can liken the behaviour of electricity to that of water (in this case, we'll ignore the recommendation not to mix water and electricity!).

Voltage (Unit: Volts; V)
Voltage is equivalent to 'electrical pressure' and can be likened to the pressure in a water tank (see diagram below). With the tank filled to point ***a***, the resulting head of water could represent 2 volts of electrical pressure at the outlet pipe. A full tank, with a greater head of water, would then represent a higher pressure of 12 volts; a practical example of this is the car battery where six 2 volt cells are joined internally to form the familiar 12V battery. Voltage is also sometimes called electrical 'potential' ~ because voltage represents the *potential* for a current to flow, provided a circuit is completed.



This tank of water serves to illustrate the concept of electrical voltage, which can be likened to water pressure. The higher the water level is, the greater the pressure of water (voltage) within the tank.

The tank's diameter also represents capacity, the flow of water represents current in Amps and the size of the outlet pipe represents electrical resistance – the smaller the diameter, the greater the resistance.

Current (Unit of measurement: Amps; A)
Electric current is measured in Amperes (A), or Amps for short. Current may be likened to the *quantity* of water flowing per hour through the outlet pipe in diagram 1. For example, a flow of 1 litre (or gallon if you like) per hour could represent 1 Amp. If the outlet pipe was larger, and the increased amount of two litres (or gallons) per hour flowed through the pipe, this would represent 2 Amps. Currents smaller than 1 Amp are usually referred to in terms of milliamps (mA; 1mA = 1/1000 Amp), for example 0.5A = 500mA. Please note that the water analogy is offered here to help understand the concepts and differences of voltage and current. In reality a complete electric circuit must of course be formed for electricity to flow.

Electrical resistance (Unit of measurement: Ohm; Ω)
All electrically conductive materials have some electrical resistance. This may be likened to the resistance that the water experiences when flowing through the outlet pipe in the diagram

above; a small pipe will have more resistance than a large one. Similarly, a thick piece of wire will have a lower electrical resistance than a thin one. This is why thick wire is used for high-current applications such as electric flight battery packs, while thinner wire is used for low current applications, e.g. servo wires. Resistance is measured in a strange sounding unit called the *Ohm*, often abbreviated to the Greek symbol Ω. A resistance of 6 Ohms may be written 6Ω, or occasionally as 6R (the R standing for Resistance in Ohms).

Internal resistance
The materials from which a battery is made all have their own electrical resistance. We call the electrical resistance of a cell its *internal resistance*. This factor is a major influence in determining how suitable a battery is for high currents.

Electric circuit
Electric current is said to flow from positive to negative. In order for a current to flow, a complete electrical circuit must be formed.

Power (Unit of measurement: Watts; W)
Electrical power is commonly measured in Watts. One horsepower is equivalent to 746 Watts. The familiar 60W household light bulb therefore consumes a bit less than 1/10 hp. To give some electric modelling examples, an indoor model might consume around 25W, a typical parkflyer perhaps 60W, while an average ‘400’-sized model might draw about 150W. By comparison, a 0.40cu in (6.5cc) glow engine might develop about 0.7Hp, or about 520W while driving a 10 x 6 propeller. A very simple equation tells us how to find the Wattage, or power flowing in a circuit:

Watts (power) = Volts x Amps.

For example, a motor drawing 10 Amps at 8 Volts is consuming 80 Watts of power:

(8 Volts x 10 Amps = 80 Watts)

Off-load and On-load
An electric current is sometimes referred to as a ‘load’. When not being used, a battery is therefore said to be in an ‘off load’ or ‘open circuit’ condition. Similarly, a battery supplying a current is said to be ‘on load’.

Cycle
A cycle is one charge and discharge of a battery (or vice versa). The **Cycle life** of a cell is the number of cycles it can provide before its performance deteriorates unacceptably.

State of Charge (SOC)
We can refer to the amount of energy remaining in a cell as its ‘state of charge’. For example, a nearly exhausted cell is said to be in a low state of charge. A cell in a low state of charge may also be said to be in a highly discharged state.

Cell Capacity (Ah)
Suppose we have a one litre water tank. This would be able to provide a flow of one litre per hour for exactly one hour before it was empty. We could say the capacity of the tank was 1 litre-hour.

Similarly, a battery that could provide a current of 1 Amp for 1 hour is said to have a capacity of one Amp-hour, also written ‘1Ah’ or 1,000mAh.

Charging Principles
When charging a rechargeable battery, current is forced ‘backwards’ through the battery (i.e. in the opposite direction to normal) by the charger. This is accomplished by connecting the positive of the battery charger to the positive of the battery, and of course negative to negative. The battery’s own voltage will oppose that of the charger, so the charger’s voltage must be higher than that of the battery. Thus to recharge a 12 Volt battery requires a charger voltage of perhaps 15 Volts. Recharging causes the chemical changes that occurred as the

battery gave up its charge to be reversed. The recharging process can be likened to connecting a high pressure hose pipe to the outlet pipe of our water reservoir, so that water is forced to flow back into the reservoir.

‘C’ Rate

This is a term used to indicate the amount of current flowing through a battery in relation to its capacity (C). For example, the 1C current for a 1,200mAh cell is 1,200mA or 1.2 Amps. The table below illustrates this concept:

Cell Capacity	C Rate				
	C/10	1C	2C	10C	20C
600mAh	60mA	600mA	1,200mA (1.2A)	6A	12A
1,200mAh	120mA	1,200mA (1.2A)	2,400mA (2.4A)	12A	24A
2,500mAh	250mA	2500mA (2.5A)	5,000mA (5.0A)	25A	50A

From the table, we can see that 1,200mA is the 1C current for a 1,200mAh battery. Notice that 1,200mA is also the 2C current for the smaller 600mAh battery. So, when using the C concept, we are specifying a current *in relation to the capacity of the battery in question*, rather than mentioning a specific current. The C rate is therefore a useful indication of how hard a battery is working. For example, a fully charged battery pack would become discharged in about one hour at 1C, or only half this time, 30 minutes if the pack was made to work twice as hard with a discharge rate of 2C.

Note that C rates apply to both charge and discharge currents. It follows therefore that C rates are also a convenient way to describe the ‘speed’ at which a battery is charged. For example, an empty battery charged at a constant 1C would *theoretically* be charged in an hour. (In practice, the charge current will need to be varied when charging LiPo cells, as we shall see later on.)

Old and new. The small early battery was rated at just 3C. Several years of development have provided modellers with some remarkable improvements. Modern high performance LiPo batteries are now able to deliver a sustained discharge current of 25C or even 30C.

How to ‘see’ electricity

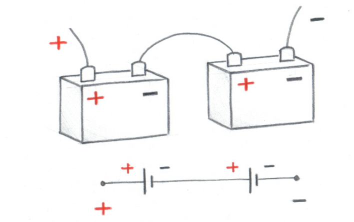
One of the main barriers to understanding electricity is that we cannot actually see it. This is why the analogy of water flowing in a pipe is useful, as we can easily imagine water flowing. Fortunately there is a means of ‘seeing’ electricity - we can measure current using an ammeter (short for amp-meter) and voltage with a voltmeter. A simple cheap digital ‘multimeter’ incorporates both of these and other functions and I highly recommend purchasing one. Such meters are often limited to measuring a maximum of 10 Amps. Many motors will consume more current than this so to measure motor currents another meter will also be required. Commercially available ‘wattmeters’ are ideal for this purpose. These are invaluable for helping avoid battery damage due to excessive discharge currents!

Chapter 2: Connecting Cells

A single LiPo cell is nominally of 3.7 volts. Two or more cells may be joined together to form batteries of higher voltage and/or greater capacity. In the earlier days of LiPo batteries, it was common to find packs made up of multiple cells joined in parallel. Today, cells are available in a greater variety of capacities including some quite large cells, so that the need to join many smaller cells is greatly reduced. For this reason, only very high capacity packs tend to employ parallel-wired cells. Almost all of today’s batteries require only series-wired cells.

Joining cells in series

Most models require a battery of higher voltage than a single LiPo cell can provide. To join cells to form a higher voltage battery, they are joined, positive to negative, and are then said to be ‘in series’. The voltage of the resulting battery is found by adding the voltages of the individual cells together. The diagram below shows a two cell battery, formed by joining two individual cells in series. Any number of cells can be connected this way to provide the required voltage, for example, two series-joined LiPo cells will give a 7.4 volt battery, three cells 11.1 volts, four cells 14.8 volts and so on. Under load, each series-connected cell will supply the same current. Joining cells in series to give a higher voltage battery may be thought of as being equivalent to raising the level of the water in the reservoir described in chapter 1.



Two 3.7V 700mAh cells shown joined in series. The resulting battery is rated at 7.4V 700mAh. This battery is referred to as being in 2S1P format, or just 2S for short.

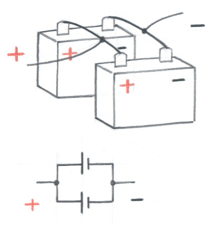
The electrical diagram underneath shows how series-connected batteries are represented diagrammatically.

A note on capacity

Clearly, the more cells a battery consists of, the more total energy it will contain. Battery capacity in the modelling world is expressed only in terms of current and time (e.g. 700mAh, i.e. a current of 700mA for 1 hour). However, the capacity of a battery made from series-connected cells is still said to be the same as the capacity of the individual cells from which it is made. Thus, the capacity of a battery comprising three 700mAh cells connected in series (3S1P format) is still 700mAh. The greater energy content of this battery compared to a single cell is reflected by the fact that the battery will deliver the same current for the same time as a single cell, but at a higher voltage and hence at a higher power (remembering that Power = Volts x Amps).

Joining cells in parallel

To join cells to form a higher capacity battery, they are joined positive to positive, negative to negative. When joined like this the cells are said to have been joined in parallel. The total capacity of the resulting battery will be equal to the capacity of the two cells added together (see diagram below). The voltage of the battery will still be the same as a single cell. For example, two 700mAh LiPo cells joined in parallel would form a 3.7V battery, enjoying an increased capacity of 1,400mAh. Similarly, three such cells joined in parallel would result in a battery of 2,100mAh (2.1Ah, i.e. 3 x 700mAh), still of 3.7V. The current demand will be shared equally by all the cells. If two cells are in parallel, each will supply half the total current; if there are three cells then each will supply a third of the total and so on.



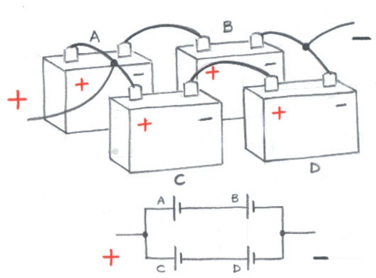
Two 3.7V 700mAh cells joined in parallel. The resulting 2-cell battery is rated at 3.7V 1,400mAh (2 x 700mAh).

Below, the same arrangement is shown diagrammatically. The positive terminal is represented by the longer line. This battery is referred to as being in 1S2P format.

Parallel joining of cells therefore allows a battery to be made which is able to supply a higher current than a single cell could manage. Joining cells in parallel is equivalent to increasing the diameter of the water reservoir, but with no change to the level of the water within it, as described in chapter 1.

Series-parallel connecting of cells

So far we have seen how to connect cells in series (higher voltage, same capacity) or in parallel (same voltage, higher capacity). It is also possible to combine these techniques to make a battery with both increased voltage *and* increased capacity. This is done by joining cells in a 'series-parallel configuration'. This technique may be used for making very high capacity LiPo packs. As the name implies, this is a combination of series and parallel connections. The simplest possible series-parallel battery is shown below, using four cells.



Four 3.7V 700mAh cells joined in a series-parallel arrangement. The resulting battery is rated at 7.4V 1,400mAh.

Below, the same arrangement is shown diagrammatically. This battery is referred to as being in 2S2P format.

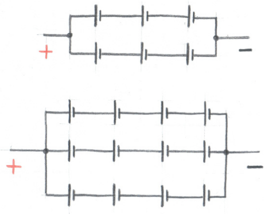
Notice that cells A and B are joined in series, and that cells C and D are also joined in series. Both of these series-pairs are also joined to each other in parallel; hence the term 'series-parallel'.

A series-parallel battery has a voltage equal to the combined voltage of each set of series-connected cells, in this case two cells are in series so the battery voltage will be 7.4V (2 x 3.7V), The capacity of a series-parallel battery will be equal to the combined capacity of each set of parallel-connected cells. In this case there are two cells in parallel and so the capacity of the battery will be 1,400mAh (2 x 700mAh). Such a battery can supply a higher current and at a higher voltage (and hence a higher power) than a single cell would be able to offer.

Battery nomenclature

Because the battery in the previous example involves two cells in series and two in parallel, it is said to be a 2-series, 2-parallel battery, more usually written '2S2P'. We can refer easily to other battery configurations in a similar way; for example a 3S2P battery would involve three cells in series, paralleled to another series of three cells, making six cells in total. Using 700mAh cells, the resulting battery voltage would be 11.1V (3 x 3.7V) and total capacity 1,400mAh (2 x 700mAh).

When cells are only connected in series, this same notation may, somewhat unnecessarily, still be used. For example, a battery comprising just 3 series-connected could be said to be in 3S1P configuration. In this case, the 1P part simply indicates that there are no further sets of cells connected in parallel. Usually however such a battery would simply be termed a '3S' battery.



Top: 3S2P battery. Here, three cells are in series (3S) and there are two sets in parallel (2P)

Bottom: A diagrammatic representation of a 4S3P battery, which consists of three sets of four cells in series

Chapter 3: Battery Characteristics

In order to lay the foundations for understanding the behaviour of LiPo batteries in particular, this chapter details the electrical characteristics that apply to all varieties of battery.

Battery Voltage
When we refer, for example, to a ‘3.7 Volt’ LiPo cell, it is important to appreciate this voltage should be considered to be a baseline or ‘nominal’ voltage. This cell is ‘nominally’ 3.7V, however its actual voltage may be either more than 3.7V or less than 3.7V, dependant upon the circumstances ~ for example we instinctively know that a battery in a low state of charge has a low voltage. The voltage of a battery will of course change more than the voltage of a single cell. A battery or cell will always be in one of three states:

- Off-load, or ‘open circuit’ i.e. disconnected from any electrical load.
- On-load, i.e. under discharge
- On-charge, i.e. while being charged

Off-Load (or resting) Cell Voltage
Let us first consider a cell (or battery) in an ‘off load’ condition. Its voltage will vary according to its state of charge, and we would correctly expect a fully charged cell to have a high voltage, and a discharged cell to have a low voltage.

On-Load Cell Voltage
When a cell (or battery) is on-load, in addition to its state of charge a second factor will affect its voltage. This factor is the electrical resistance of the cell itself, which we call its internal resistance. When a current starts flowing the effect of internal resistance is that the cell’s voltage will be slightly reduced compared to it’s off-load voltage. The cell is then said to have suffered a *voltage drop*. The amount of voltage drop will depend both on the internal resistance of the cell and the amount of current flowing:

> The higher the electrical current (load), the greater this voltage drop will be.
> The higher the cell’s internal resistance, the greater the voltage drop will be.

To clarify this important concept, let us now consider some examples:

> Low loads A cell of low internal resistance under a very low load suffers only a very small voltage drop. A cell of higher internal resistance under the same load will show a higher voltage drop. In both cases the drop will be very small if the current is very low.
>
> Higher loads A cell of low internal resistance under a heavy load will suffer a larger voltage drop compared to being under a lighter load. A cell of higher internal resistance under a heavy load will suffer the greatest voltage drop of all.

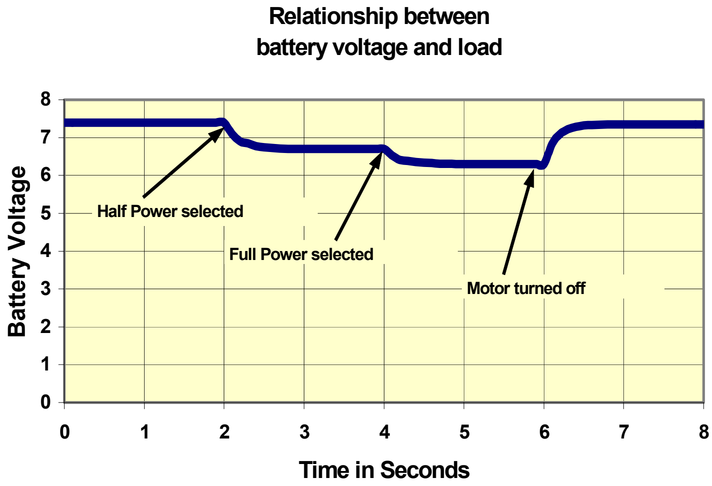
The larger a cell is in terms of its physical size and/or its capacity the lower its internal resistance will tend to be. Batteries with a relatively low internal resistance are legitimately given a high C rating.

All else being equal, the lower the internal resistance of a particular battery is, the *more suitable that battery is* for high current applications such as electrical powered models. Thus, larger cells are generally better suited to higher currents than small ones are.

Note that once we stop taking current from a battery, its voltage will begin to rise back to the voltage determined by its state of charge. An important point to remember is that a battery’s internal resistance will only affect its measured voltage when it is on load. Some practical examples of voltage drop are: (a) When a lead-acid battery is used as the power source for a LiPo charger, its voltage drop under load (caused, remember, by its own internal resistance) means the charger will have to operate on a slightly reduced battery voltage. This effect can easily be seen on chargers which display the input voltage. (b) In the case of an electric LiPo powered model, the voltage drop within its drive battery (again caused by the battery's own internal resistance) will mean a reduced voltage is available at the motor.

Voltage recovery

As soon as a load is removed from a cell it will immediately start to 'recover' back to the off load voltage determined by its state of charge. The graph here illustrates both the voltage drop and voltage recovery effects that we have just discussed. In this example (a 2-cell LiPo in a part discharged condition) the off load battery voltage is 7.4 V, and it falls to about 6.7V when the motor is set to half power after 2 seconds. The voltage falls further to about 6.3V when full power is selected at 4 seconds. At 6 seconds the motor is switched off and the battery voltage then starts to rise again towards the off-load voltage of 7.4 Volts.



Battery Voltage under charge

The voltage of a cell under charge will appear to rise; the higher the charge current is, the higher the cell's apparent voltage will be. This characteristic is easily observed on any charger displaying battery voltage. Cell voltage under charge is a somewhat artificial figure because what is really being measured is the output voltage of the charger necessary to drive the required charge current ~ the higher the charge current required, and the higher the internal resistance of the cell under charge, the greater the charger voltage needs to be.

Internal resistance

All electrically conductive materials present some resistance to the flow of current. The materials from which batteries are made are no exception, so not only does a battery provide a voltage, but it also has some resistance as well. The resistance of a cell is termed internal resistance, since it's inside the cell. Internal resistance is responsible for the tendency of batteries to become warm in use, and its effect is especially noticeable at high discharge currents. An example of electrical resistance is the common incandescent light bulb, in which the current causes so much heat to be generated in the bulb's filament that it glows white hot.

Coming back to batteries, the heat generated during use due to internal resistance wastes part of the cell's energy and represents a loss of efficiency. The amount of heat generated depends, in a similar way to voltage drop, upon both the internal resistance of the cell and the current flowing:

- The higher the current, the greater the amount of heat generated.
- The higher the internal resistance, the greater the amount of heat generated.

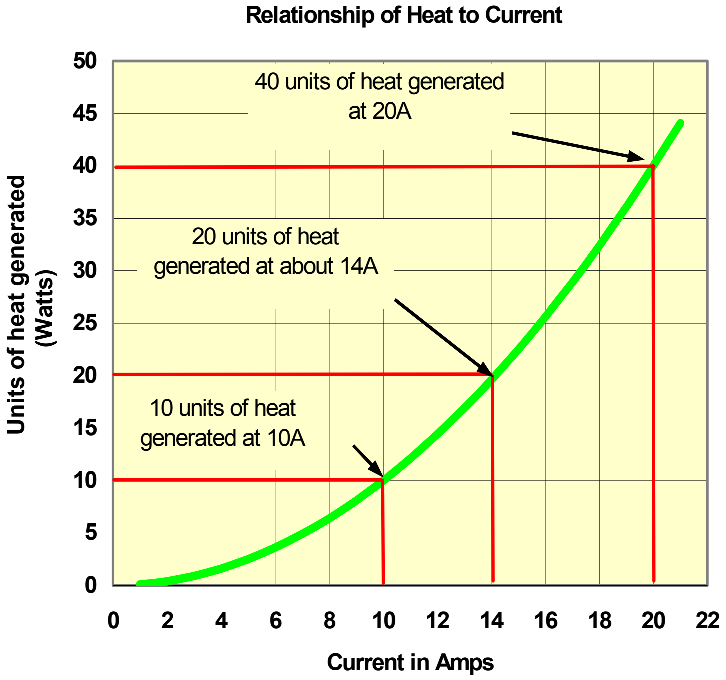
A note to the mathematically minded

The amount of heat is found using the formula: Heat = Amps x Amps x Resistance. This can also be expressed as Heat = I^2R. Confusingly, the letter 'I' is often used in electrical calculations to represent current, and not the letter A as we might expect.

What does this mean for us in practical terms?

In practical terms, what this formula shows us is that small increases in current will produce disproportionately large increases in the amount of heat generated, as illustrated by the graph below. This is a most important point to bear in mind any time we are thinking about electric power systems.

Let's look at a practical example: Supposing a model draws 10A with a particular prop at full power. The prop is then changed for a larger one. This causes the current drawn to increase to about 14A. The heat generated inside the battery will double, even though the current has only risen by about 40%. If an even larger prop is fitted so that the current becomes 20A, the heat generated will be *four times* what it was at 10A. The graph below illustrates this. Clearly, this means there are some important implications for the cooling requirements for your LiPo battery.



C ratings again

The current capability of a cell is determined to a large part by its internal resistance. If a cell is to sustain a high current without overheating, it must have a low internal resistance. So, provided cells are rated accurately (not always the case), those that are rated at say 30C will have a lower internal resistance than those rated at 20C.

All components are affected

This 'law of heat generation' applies to all of the electrical components in a model's power system. So not only will the battery generate heat as a result of the current flowing through it, but so also will the electronic speed controller (ESC), the motor, the connectors and even the power system's electrical wiring. In each case, heat will be generated according to the same principle.

What's the answer to the 'heat problem'?

It's impossible to eliminate the heating effect when current flows. Therefore, in order to minimise the heat generated (which is wasted energy) all we can do is to keep the current to a minimum. The heat/current relationship graph also shows why it's important to ensure sufficient cooling is provided for the battery, ESC and motor particularly at higher current values. The basic resistance of an individual LiPo battery is effectively a fixed quantity and is not a factor over which we have much control, except when deciding which battery to buy.

Chapter 4: Introduction to LiPo cells

When LiPo cells first reached the modelling market some years ago, they appeared to be just what electric aeromodellers had been crying out for ~ a lightweight, high voltage cell with a high capacity. However, LiPo cells soon proved to be somewhat delicate, requiring careful handling. For the same weight a LiPo battery contains several times the stored energy as a nickel-based cell and therefore has a much higher energy/power density.

LiPo cells are nominally rated at 3.7V and are available in a wide range of capacities. They must be kept within a safe voltage range (3.0 to 4.20V) at all times. To ensure this they require careful charging and handling. Unlike nickel-based types, the consequences of mistakes with LiPo cells are potentially much more serious and include battery fires so safety issues are very important with LiPo cells. The very important topic of this safe voltage range is expanded upon in the next chapter.

The internal resistance of a cell is the main factor in determining its ability to sustain a high discharge rate. Modern cells, especially those of high quality, generally have a low internal resistance. Although this allows the cells to sustain high discharge currents, the charge current is still generally limited to a low value. Cells able to withstand relatively high discharge currents may be known as 'high rate' cells.

What's inside a Lithium Polymer cell?

LiPo cells are said to be of 'plate' construction because they are made up from a number of thin parallel-connected plates, similar to the thicker plates of the familiar car battery. This produces cells with a low internal resistance, so LiPo cells are generally well suited to high discharge rates. The electrolyte is a thin rigid sheet of polymer which helps to gives the cell some resistance to bending. However because the case of the cells is simply a thin foil of metalised Mylar they are easily damaged by impacts or other physical mishandling.

A collection of LiPo batteries. The delicate silver metalised Mylar skin of the cells may easily be seen. Heat shrink sleeve is used to hold the cells securely and to cover the cell's connecting tags. Note also the use of a protective sleeve on the positive lead of the red battery, which is fitted with 2mm 'Gold' connectors

LiPo cells are unable to release any excess pressure that may build up inside the cell. The soft pouch of the cell will therefore expand or 'puff up' when under high pressure, such as if they are overcharged. In an extreme overcharge situation, the cell will balloon up so much that it will eventually explode and burn.

A quick comparison

Property	**NiMH**	**LiPo**
Nominal voltage per cell	1.2V	3.7V
Internal resistance	Moderate	Considerably lower
Normal max continuous discharge current	Up to approx 10C	Up to 30C (as rated)
Normal maximum charge current	1C – 2C	1C (or higher if approved)
Capacity per unit weight	Moderate	Much higher
Overall safety	Very high	Much lower if not used correctly
Overcharging	Allowed at C/10 only	Dangerous
Tolerance to over-discharging	Limited	Very poor
Cycle life/Durability	Good	Lower

An example of a swollen or 'puffed up' LiPo battery. When undamaged, this battery had a neatly rectangular shape. However, the pack is no longer flat, and its straight edges are long gone.

This cell developed this condition while in storage, and it's no longer safe to use. It was stored in a fully charged condition, which may have accelerated the cell's degradation.

To charge lithium batteries, a specially designed LiPo-capable charger is absolutely essential to avoid overcharging cells and the consequent risk of battery damage, fires or even explosions. Similarly, the use of an electronic speed controller (ESC) specifically designed for use with lithium cells is also essential. Used correctly, these will not allow the battery to be over-discharged.

Memory effect
Lithium batteries don't suffer from the so-called 'memory effect'.

'C' Rating
Modern LiPo cells are capable of very high discharge currents. Some cells are rated for a sustained 30C discharge which would exhaust the battery in only 2 minutes. For a 2,500mAh pack this is equivalent to a continuous 75A – this is a very high current indeed. However, very high currents will shorten a battery's lifespan. This issue is discussed in detail later on.

LiPo lifespan, (cycle life)
The nature of LiPo cells, combined with the relatively demanding modelling environment means they usually only enjoy a relatively short cycle life. A good quality LiPo battery if treated well could achieve 200+ cycles. This represents quite a lot of flying – that's 4 flights every week for an entire year. If each flight was only 6 min in duration, the accumulated flying time would total 20 hours. Sadly most models never last long enough to accrue this many flights! LiPo cells, whether they are used or not, will gradually deteriorate over time.

Lifespan definition
Some people define the lifespan of a LiPo battery as when its capacity falls to 80% or some other proportion of its stated capacity. Depending on the way it's used, this situation can occur quite soon. My own definition is a little more flexible – provided I am getting safe and reliable use from a LiPo, I keep it in service. Whatever definition you choose, essentially the life of a LiPo ends when it's no longer able to provide you with the service you need.

Learning new habits

Some practices and habits you may have learned while using other battery types must be unlearned when working with LiPo cells. For example, you may have already discovered that NiCd and NiMH cells are relatively tolerant of mistakes such as accidental overcharging, over-discharging and physical damage. Generally, the worst that happens in overcharging or reverse charging episodes is that cells become hot – if left for a while they will cool down. In severe cases, their safety vent may operate and some electrolyte will be vented off, relieving any excessive internal cell pressure (explosions, while possible are rare). In such cases, although the cell itself may have suffer damage, generally no harm will have occurred outside of the cells.

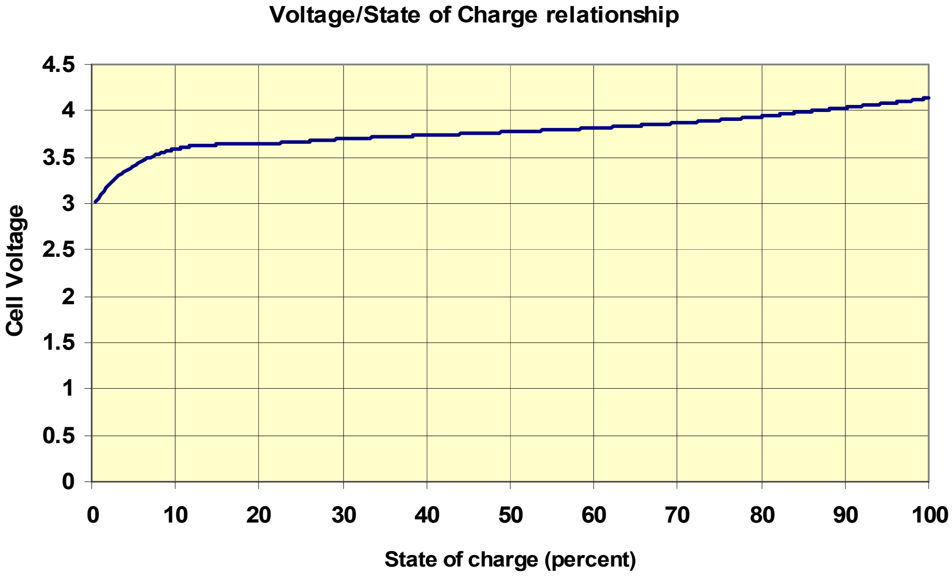
By comparison, the same kind of abuse will be MUCH more serious in the case of LiPo cells, with consequences including battery fires. Remember to stay alert to the needs of LiPo technology.

Chapter 5: Characteristics of LiPo cells

Nominal Voltage
The nominal or baseline voltage of a LiPo cell is 3.7V. This nominal figure serves as an industry standard reference and is useful as a comparison with other cell types. For example, a nicad (NiCd) or Nickel Metal Hydride (NiMH) cell has a nominal voltage of 1.2V, and so we can see that a single LiPo cell is roughly equivalent in voltage to three NiMH cells linked in series.

Earlier, we saw that a battery will always be in one of three states; off-load, on-load and on-charge. Let's now look at how the voltage of a lithium cell will respond to these conditions:

Cell Voltage Off-Load
The off-load voltage of a LiPo cell will of course vary according to its state of charge. The relationship between a single cell's state of charge and its voltage is shown in the graph below:



Several noteworthy points can be extracted from this graph:

- The voltage of a fully charged cell is 4.2V and 3.0V for a fully discharged cell. However, for improved cell life a preferred minimum is 3.3Vpc. This issue is discussed later on.

- The line representing battery voltage is relatively flat, especially when the cell is between about 15% to 60% charged (left hand part of the line). This indicates how little the battery voltage changes compared to its state of charge, making it difficult to accurately tell the state of charge of a cell simply by measuring it's off-load voltage.

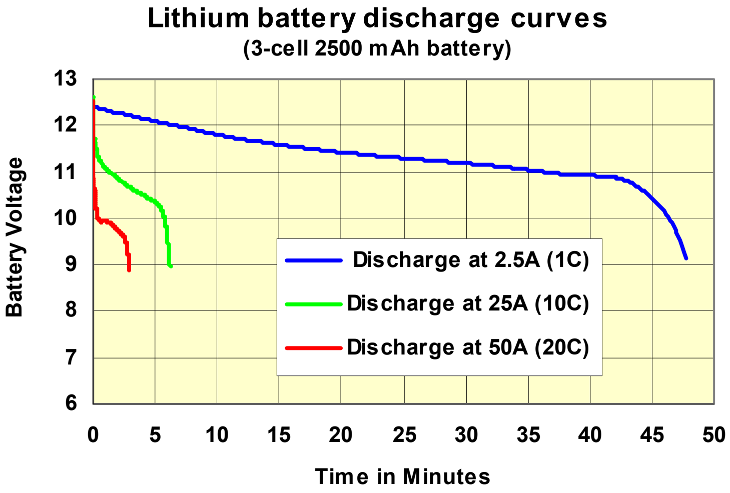
- The cell's voltage drops quite sharply as the battery reaches a fully discharged condition. The difference between 3.0V and 3.3V represents only about 5-6% of the cell's stored energy. It's not worth trying to extract this small quantity given the consequent reduction in cell life.

A 2-cell LiPo battery minus its heat shrink sleeve, showing the cell's connecting tags.

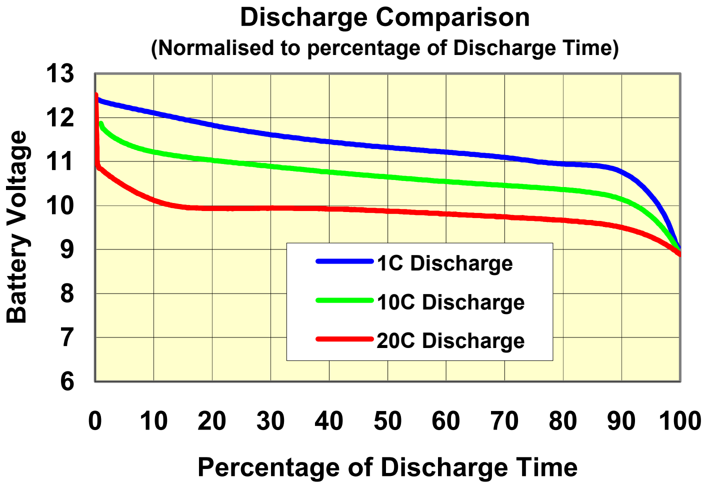
Cell Voltage On-Load

The on-load voltage of a LiPo cell will vary according to its state of charge as well as the current the cell is supplying. The diagram below shows the results of testing a lithium cell at different discharge currents. The lines on the graph are known as 'discharge curves', and the shape of the curves tells us a lot about the characteristics of the cell.

The pack tested to generate the graph below was a well used 3 cell 2,500mAh example, rated at a maximum discharge current of 20C. The battery was discharged using three different resistive loads. The blue (upper) line represents its voltage as it was discharged under a very light load (discharge current slightly over 1C). The green line represents the same pack at a moderate current (approx 10C) and the red line at the rated maximum continuous current (approx 20C) for this particular battery.



The higher the discharge current (i.e. the greater the load), the more quickly the battery became exhausted which is exactly what we would expect. At about 1C, the battery lasted for 47 min, at 10C it lasted 6 min and at 20C under 3 min. The battery didn't become warm during the low current test. At 10C it became slightly warm, while at 20C it had become very warm by the end of the test. To make further discussion and comparison easier, the same data are presented in the new graph below in which the horizontal axis now shows the discharge period in terms of percent discharged instead of time.



The pack starts off fully charged at 12.6V (i.e. 4.2V per cell, or 'Vpc' for short) for each test. In every case the cell voltage starts to drop sharply as the cell approaches 3.0V (i.e. 9.0V for the 3-cell pack), which is the absolute minimum safe voltage.

The 3-cell pack used has a nominal voltage of 11.1V (3.7Vpc). Notice that under a light load, the voltage remains above this figure for almost the entire discharge period, showing that the battery suffers only a small voltage drop due to its internal resistance. Battery voltage therefore remains close to the off-load voltage appropriate to its state of charge.

However, at 10C the pack is unable to maintain this nominal value for most of the test. At this heavier load, we can see that the cell suffers a greater voltage drop since the green line is below the blue one. The lines are parallel showing that the greater effect of internal resistance at a higher current.

At 20C the voltage drop is even greater. (Note the 20C line is not quite parallel to the other two ~ this because a significant amount of heat is developing within the cell. This effect is discussed in greater detail later.)

The safe voltage range for LiPo cells

It was earlier stated that LiPo cells must at all times be kept within a particular voltage range. This safe range is generally considered to be an absolute minimum of 3.0Vpc (3.3Vpc is a safer minimum) and a maximum of 4.2Vpc. If cells are allowed to venture outside of this range, they will suffer damage and be at risk of catching fire.

In the early days of LiPo batteries, when their internal resistance was higher, a minimum on-load voltage of 2.5Vpc was sometimes specified, as the cells would tend to recover towards 3.0Vpc once the load was removed. For modern low resistance cells, an on-load voltage of 3.0Vpc is an absolute minimum. It is probable that as new cells achieve ever lower internal resistances, a slightly higher minimum voltage will come to be stipulated.

Maintaining LiPo cells within this safe voltage range is extremely important, and this matter must be kept in mind at all times when using (or charging) LiPo cells. Although the range 3.0 - 4.20V is safe, we will see later on that there are worthwhile benefits in keeping the cells within a slightly more conservative voltage range.

Why must cells not be allowed to exceed 4.20 volts?

A brief answer:

The battery voltage must not be allowed to exceed 4.20Vpc otherwise internal damage will occur, with the possibility of the battery catching fire, especially if it becomes excessively warm.

A more detailed answer:

The negative plates (or cathodes) of LiPo cells are rich in a substance called lithium cobalt dioxide. Unfortunately, lithium cobalt dioxide is not thermally stable, meaning that the chemical bonds holding this substance together become weak at high temperature. (These weak bonds can be thought of as being similar to glue that cannot stand high temperatures. If the cell becomes too hot the glue will fail, allowing the bonds to fail.)

The cell’s inherently poor thermal stability is improved by deliberately adding an excess of lithium to the cell’s negative plates (or cathode) during manufacture. However, this excess lithium will only stay where it belongs provided the cell is not overcharged. From approximately 4.25Vpc (i.e. an overcharge of only 0.05Vpc or 1/20th of a volt) this excess lithium will start to move from the negative plates (cathode) on to the positive plates (anode), by the process of electro-plating. If overcharging is continued, this excess lithium is progressively lost, until the lithium cobalt dioxide is no longer thermally stable – in this state, the cell becomes very vulnerable to the effects of raised temperature. If any part of the interior of a cell in this condition then reaches the critical temperature (perhaps only 160°C/320°F, or even lower depending on the amount of lithium which has been deposited on the anode), the lithium cobalt dioxide will break down, releasing oxygen within the cell as it does so.

The now oxygen-rich cell interior will generate further heat, releasing even more oxygen, thus causing even more heat to be generated; and a dangerous, self-sustaining process is now occurring also known as ‘thermal runaway’. All of the ingredients for a fire have been brought together: oxygen, a source of heat and some highly combustible material; consequently once the cell becomes hot enough it will burn with a fierce flame.

Why cells must be kept above 3.0V.
If a cell is allowed to go below its minimum safe voltage, as would happen if it was over-discharged, traces of copper would be deposited in the region between the positive and negative plates. The longer a cell is kept in an over-discharged condition, and the more deeply it has been allowed to become over-discharged, the more concentrated these deposits are likely to be and hence the greater the damage to the cell. Copper is of course electrically conductive. A small quantity of copper may cause a high resistance bridge between some of the plates resulting only in a loss of capacity. However if enough copper is deposited a low resistance bridge, or 'shunt' may form and an internal short circuit may result.

The nature of this process is unpredictable, so a short circuit might for example only be completed when the cell changes temperature. Thus any resulting short circuit will not necessarily occur while the cell remains in a discharged condition and may occur during or after recharging. An internal short circuit cannot of course be seen or stopped and will cause the cell to get hot, the result of which is likely to be a fire for the same reasons as mentioned for overcharging.

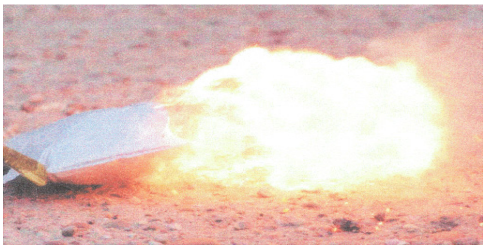


Photo by kind permission of S. Sheldon & M. Orbell

This LiPo cell has just ruptured during overcharging, under test conditions. The normally flat, rectangular cell case has swelled up under pressure and burst. A powerful but short-lived long jet of flame is starting to develop.

Bearing the above in mind it's clear that for greatest safety batteries which have been allowed to become significantly over or under charged should be discarded. The price of a replacement battery is rather less costly than the damage a battery fire could cause!

Internal resistance
We discussed earlier that LiPo cells have an electrical resistance of their own and that this resistance is one of the factors responsible for the battery becoming warm in use. The internal resistance of all types of cell, including and in fact especially LiPo types, is actually a changeable quantity, depending both on temperature and state of charge.

Effect of temperature
Internal resistance will be lowest when a battery is warm. LiPo packs often exhibit a poor performance when they are very cold. Performance may improve if they warm up sufficiently in use. Its bad practice to rely on this effect as using cold batteries may shorten their life. Pre-warming batteries is a much better practice so when flying in cold conditions it is advisable to keep batteries warm until just before using them. Pockets are not suitable for this purpose due to the possibility of fire following a short circuit. It's also worth considering reducing the supply of cooling air to cells in models in cold conditions. When very cold (below 0°C/32°F) crystals will tend to form inside the cells. If an attempt is made to charge a very cold battery it could literally explode. Most manufacturers do not recommend charging a battery which is below 10°C/50°F and definitely not below 0°C/32°F.

Effect of state of charge
A cell's internal resistance will be lowest when it is in a high state of charge. In a very low state of charge its internal resistance will increase sharply. This characteristic is responsible for an increased heating effect as the battery reaches an exhausted state and is an additional reason why it is wise not to fully discharge cells.

Chapter 6: LiPo safety

Overview of LiPo battery safety

Few modelling subjects have generated as much interest in recent times as the safety of lithium batteries. It's fair to say that in terms of safety modellers are worse off with LiPo batteries than other types. Understandably this has created 'LiPo battery fear'. Some modellers have purchased LiPo batteries, but due to misinformation have not yet found the courage to use them!

The aim in this chapter is to raise your awareness of the possible hazards and to help you make sure that your LiPo batteries aren't a danger to you, your family or your property. Provided they are used correctly and treated with care and respect you can expect good service from them.

Because LiPo safety is such an important subject this entire chapter focuses on safety issues. This chapter is deliberately positioned here before we move on to the practical aspects of LiPo battery usage. Before using your batteries please make sure that you have read, digested and fully understood the instructions that will have been supplied with your cells, and preferably also the entire contents of this guide, especially this chapter.

Please bear in mind that although the purpose of this chapter is to highlight the safety issues relevant to LiPo batteries it's not possible to neatly package every item of information relevant to safety within just this one chapter. For this reason, *all* chapters must be considered to be relevant to safety, and should be considered alongside the information within this chapter.

The modelling environment

Lithium batteries are in many consumer products such as lap top computers, mobile telephones and so on. In these types of applications, lithium-Ion (Li-Ion) batteries are the type generally used. Each Li-Ion cell within a battery is carefully monitored and controlled by sophisticated 'protection & charge monitoring' circuits (PCMs), designed to prevent any possibility of a cell going outside of its safe voltage range, or being mishandled in any other way. Charge and discharge rates are also comparatively low. For these reasons battery accidents are very rare in lithium powered consumer equipment.

In modelling applications LiPo batteries are supplied without the luxury of PCMs. This means that their safe voltage range can easily be exceeded. Charge and discharge rates are typically much higher so for batteries the modelling environment is therefore much harsher and the risk of a battery accident is consequently much higher.

Furthermore the possible *consequences* of LiPo battery accidents are more serious than for other types. For example an overcharging episode with a nickel-based battery might only cause it to get hot, but the same event with a LiPo battery could result in a fire.

LiPo familiarity

Familiarity in any area of life can lead to a failure to concentrate or pay proper attention. Make sure that as you build experience with LiPo batteries that you continue to take care! Don't let yourself be distracted when working with LiPo batteries, and please don't fall into the trap of thinking 'it'll never happen to me'!

Battery documentation

In contrast to other battery types, LiPo batteries are generally supplied with documentation carefully detailing the necessary precautions. This is a very clear indication that battery manufacturers recognise the importance of LiPo safety.

Please make sure you've read and thoroughly understood the safety documentation supplied with your LiPo battery, even if you don't intend to use it immediately. In the unlikely event that no documentation was supplied, it's recommend that you obtain some from the place of purchase.

Please note that even very experienced modellers have made mistakes when charging LiPo batteries. The best solution to the safety problem is simply to cultivate good habits and develop a solid understanding of LiPo cells.

What could cause a LiPo battery fire?

A LiPo battery fire can occur when any part of the cell becomes excessively hot. Some possible reasons include over charging, over discharging, using an unbalanced pack, excessive discharge current, external short circuits, crash damage and storage in an excessively hot place. Whatever the reason once a cell becomes sufficiently hot, oxygen will be released within the cell. This will in turn cause more heat to be generated, resulting in thermal runaway and a fire.

Cause 1: Overcharging

A battery that's been overcharged is more likely to release oxygen internally which will increase the chance of a fire in a hot battery. At best, very slight overcharging – i.e. say only to 4.26Vpc and for only a few minutes, before the cell is immediately discharged back to a safe level - might result only in minor cell damage. More serious overcharging will cause greater damage and a higher risk of fire. Overcharging can also result in an internal short circuit. LiPo batteries contain a great deal of energy, so if an internal short does occur the release of a substantial quantity of energy can itself cause a fire.

Cause 2: Over discharging

At best over discharging may result only in a loss of capacity and/or performance. Over discharging has been known to cause batteries to 'puff up', become hot and even catch fire. Over-discharging can be prevented by good operating and storage practices and these are described later on.

Cause 3: Using an unbalanced pack

The most essential battery maintenance is to ensure that each cell in a battery is in a very similar state of charge to its neighbour. This is accomplished by using balancing equipment. The cells in an unbalanced pack are liable to be over charged and/or over discharged when used without a balancer.

Cause 4: Excessive discharge current

Excessive discharge current can cause the interior of a battery to reach a high temperature, even if the exterior is cooler. High temperatures are bad for battery life and in an extreme case may lead to a fire. An excessive discharge current can also cause a cell to 'puff up'. The most extreme example of an excessive discharge current is of course a short circuit.

Cause 5: Short circuits

Short circuits occur when the positive (red) and negative (black) wires of a battery become directly connected to each other. In this circumstance a very high current can flow quickly causing the inside of cells to become hot. Short circuits represent a genuine fire risk and even if fire doesn't result will cause the battery to suffer permanent internal damage. Short circuits can be either external to the battery, for example by its connectors touching, or internally, as could happen if a charged battery were damaged by something piercing its walls or as a result of an over charging or over discharging episode. Short circuits must be avoided at all costs. Even a short circuit lasting for only a fraction of a second or so has been known to cause a cell to quickly swell up. Short circuits lasting for longer than this represent a real risk of a fire; a period of as little as a few seconds may be enough to cause a fire.

Please be aware that rings can cause short circuits if battery connectors come into contact with them. Gold rings which are involved in short circuits will allow a high current to pass, making the ring get very hot very quickly. The resulting painful blister may well mean that the ring will need to be cut off in a hurry.

Cause 6: Crash damage

The Mylar pouch which encases LiPo cells is easily dented. Very minor exterior damage of this type is usually tolerated, however if the cell becomes heavily dented, bent or punctured then internal damage can result. An internal short circuit is then a possibility. This fragility is an unavoidable aspect of LiPo ownership so ensure your packs are well protected from physical damage while being used or stored.

Any LiPo that has sustained any kind of impact or has become swollen should be moved immediately to a fireproof location and be kept under observation for at least 30 minutes. This is because any fire may not break out immediately. Please note that this advice also applies to a battery that has suffered any kind of short circuit or crash, even if it still looks okay because any internal damage may not be apparent from outside. Several fires have been caused by damaged packs breaking into flame some time after an impact.

It's risky to continue to use a battery that has sustained damage. If it's suspected that cell damage is severe enough to be dangerous, the pack should be disposed of even if it still appears to work satisfactorily.

Punctured LiPo batteries give off a slightly 'sweet' smell. This odour is toxic and should not be deliberately inhaled. Its presence is a reliable indication of battery damage. Punctured cells will absorb atmospheric moisture, and this will quickly cause the cell to fail. This moisture may be visible under a pack's heat shrink insulation.

Cause 7: Storage in an excessively hot place
Cells which are stored in a hot environment such as the dashboard of a car during a hot summer day may catch fire. Always keep batteries away from sources of excessive heat.

During a LiPo battery fire
Once started, LiPo battery fires cannot be put out because the oxygen used in combustion is generated internally. Fires are generally fierce but last only for a few seconds. Although it's useless to attempt to put such a fire out a CO² (not water) fire extinguisher or a bucket of sand may be useful in limiting damage to other nearby items. Never apply water to a LiPo fire as this will only make matters worse – it's like adding petrol (gasoline).

LiPo batteries will burn with an intense heat, (up to around 700°C or 1,300°F), and any fire must run its course until the battery and any nearby combustible material is reduced to a pile of ash.

If a LiPo battery does catch fire, toxic chemicals will be released. Make sure you don't breathe in any of the fumes or allow any part of the cell's interior to come in to contact with your skin - just keep your distance and wait for the fire to stop. If you do accidentally breathe in any of the fumes, or if your skin comes into contact with any part of the cells interior, seek medical advice at once. If a LiPo fire occurs in an enclosed environment such as an indoor flying hall, the building should be evacuated immediately.

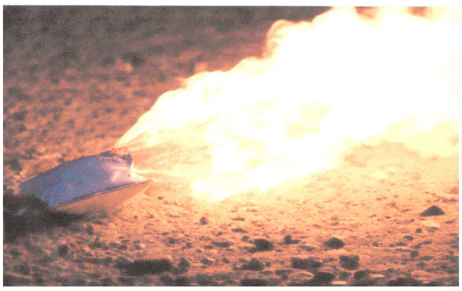


Photo by kind permission of S. Sheldon & M. Orbell

A LiPo battery fire cannot be put out. The developed flame in this example totals several feet in length, even though the single cell is just a few inches long.

After a lithium battery fire
Don't touch any of the contents of the battery or breathe any of the fumes given off. If a fire has occurred in an enclosed space then it must be thoroughly ventilated first. Wearing gloves, scoop up the remains of the battery using pieces of card or wood for example and place in a suitable fireproof container for disposal along with the gloves, which should also be discarded

due to the probability of contamination. For obvious reasons, make sure the fire is really out before using flammable materials such as card or wood to deal with it!

Handling damaged cells
If you need to handle a damaged cell, or one that is suspected to have sustained damage, put on protective gloves first. The reason for this is that cells may contain *extremely* toxic chemicals. Since we cannot know what these are protection is essential. If you have any kind of health & safety concerns involving LiPo batteries, seek medical advice at once.

Time delay
There will usually be some warning of an impending fire, the battery will first swell or become 'puffed'. It will then become warm to the touch and then hot before catching fire. However, a puffed cell does not always catch fire. Please be aware that battery fires can occur up to 30 minutes or more after a cell has sustained damage, from any cause such as a short circuit, internal damage resulting from a crash, an overcharging episode and so on. Therefore, if cells are carefully monitored, some warning of a problem will be noticed. This time lag is another good reason why cells should always be stored in a fireproof container.

Safety precautions for storing and transporting LiPo batteries
Batteries are best stored and transported in a suitable fireproof container such as a metal box. Ensure battery leads cannot short out against the box sides by insulating them. This can be achieved by lining it with a non-conductive material. The container must also be ventilated otherwise a dangerous pressure will build up in the event of a fire.

The box should in turn be kept outside of inhabited accommodation in a cool, dry, fireproof and secure location. Don't allow LiPo batteries to be stored in sub zero (0°C/32°F) temperatures.

Always store LiPo batteries away from children and any adults who are not familiar with LiPo battery safety matters. In most households this will mean that only you should have access to the LiPo batteries used for your modelling. It is recommended to fit a smoke alarm in any place used to store or charge LiPo batteries.

Never charge LiPo batteries inside a vehicle, especially one that is moving and be aware that LiPo batteries left inside a car in direct sunlight can become dangerously hot.

An ammunition box is an excellent receptacle for cells. These may be easily obtained from army surplus stores. Ideally, no more than one battery should be stored per container; this is to ensure that if one battery were to catch fire, the others will not add to the resulting inferno. This box contains rather more than one pack!

Transporting batteries on aircraft
Lithium batteries which are not installed in consumer equipment are classed as dangerous cargo by airlines. Permission must be gained from the airline before transporting batteries on commercial aircraft. Take every possible safety precaution – fires on board aircraft are very dangerous.

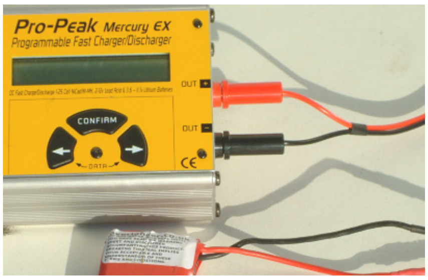
Chapter 7: Charging LiPo batteries

Most accidents involving LiPo batteries occur during charging. That said, charging LiPo batteries is a relatively low risk activity provided it is carried out correctly. Study your battery and charger instructions carefully and charge only as advised by the manufacturers.

Charge leads

Charge leads should not be too thin, or longer than 12 in. (300mm) otherwise your charger may not work correctly. Some chargers require a separate detachable charger-to-battery lead. These often have unprotected 4mm plugs at the charger end. The plugs will become live if the lead is connected to the battery alone and could easily touch, causing short circuiting of the battery. A simple precaution against this risk is to leave the charger-to-battery lead permanently connected to the charger. Alternatively, always connect the charger–to-battery lead to the charger before connecting a battery, and always disconnect the battery before disconnecting the charger-to-battery lead from the charger itself.

The danger ………



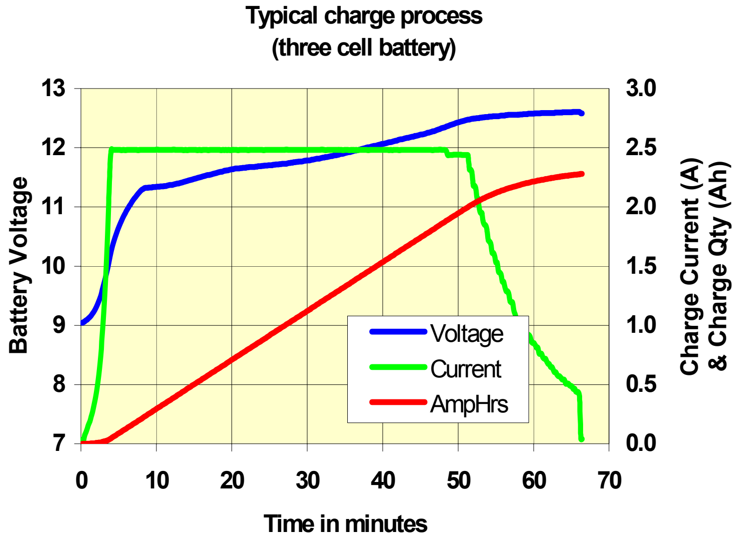
….. and the simple solution

Overview of the LiPo charge process

LiPo cells have two important requirements; firstly, charge current needs to be limited to a safe value (typically a maximum of 1C) and secondly, cell voltage must never exceed 4.20Vpc (Volts per cell). For these reasons LiPo batteries require a different charging technique to other cell types and must only be charged using a LiPo-compatible charger. It is unsafe to use a charger designed for other cell chemistries with LiPo batteries.

LiPo charging

The control process used by most LiPo chargers[1] is essentially consists of three distinct phases – charging starts (a) with a gradually increasing charging current (some chargers skip this phase), changing to (b) charging at constant current, changing to (c) charging at a constant voltage, more or less. The graph below, created using a Schulze Chameleon isl 6-330d to charge a 3-cell 2,500mAh pack illustrates this process:



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[1] Astro Flight 109 software works slightly differently.

Graph parameters
The graph above shows the three parameters of most interest during charging – voltage, charge current and the charge quantity (i.e. capacity) returned to the battery. Time is represented by the lower scale.

- Voltage is represented by the blue line. The values indicated by this line are found with reference to the left hand scale. For example, we can see that the battery starts the charge process at 9.0V.

- Charge current is represented by the green line which is associated with the right hand scale for this parameter. The right hand scale applies, showing that this varies between 0 and 2.5 Amps during charging.

- Charge quantity, or the capacity returned to the pack is shown by the red line and is also associated with the right hand scale. Just for the moment, we can ignore this parameter.

Let's now look at how charging progresses:

Phase 1 – charge current is gradually increased
During phase 1 the charge current (green line) is gradually increased by the charger until it reaches the required value, in this case 2.5A. This current is equivalent to 1C for this 2,500mAh pack and the graph shows this phase lasts for 4 min. Battery voltage rises throughout this phase, becoming about 10V as phase 2 is entered:

Phase 2 – charging at a constant current (CC phase)
Phase 2 of the charge process is known as the constant current phase. In this example, a constant charge current of 2.5A is maintained as indicated by the horizontal green line. The voltage of the battery continues to rise during this phase and is monitored by the charger. As the voltage approaches the maximum safe value of 4.2Vpc (12.6V in this case) the charger will start to reduce the charge current in order to prevent the voltage from becoming excessive. When this occurs (after about 48 min in this case, when the battery is about 85% charged) phase 3 may be said to begin.

Phase 3 – charging at a constant voltage (CV phase)
As the battery nears its fully charged state, the charge current is further reduced so that its safe maximum voltage is very gradually approached. This charging phase is said to be the constant voltage phase, even though the cell voltage is actually rising very slowly. When the charge current has been reduced so much that it has become equivalent to around C/20 (may vary depending on charger), the cell is considered fully charged and charging is terminated. The graph shows that this takes place at about the 66 min point.

Charge quantity
The charge quantity line (coloured red) line reveals the energy returned to the battery during the charge process. It can be seen that a total charge quantity of about 2.2Ah (2,200mAh) is supplied to the battery during this charging episode. The reason it is not 2,500mAh, the stated capacity of the pack, may be for a variety of reasons – perhaps the battery was fully discharged to begin with, maybe the battery's capacity has fallen, and/or it was over-stated in the first place.

Notice that by the time that phase 2 is concluded, the pack is already more than 80% charged (nearly 2.0Ah in this case). If a full charge was not required, it would be quite possible to stop charging and use the battery at this point saving the 14 min that was be required to complete the charge process.

Cell voltage at conclusion of charge
Because the charge rate will have fallen to a very low value by the time the charge process is terminated, cell voltage will not decay very far once charging has stopped, in contrast to other cell types using higher end-of-charge current values such as the NiMH variety.

An overview of charge rates
Most LiPo batteries are rated for a maximum charge current equivalent to 1C, even though much higher *dis*charge rates are safely possible. The restriction on charge rates is to do with the chemistry of recharging amongst other factors. Some computer-controlled chargers restrict the maximum allowable charge rate to 1C when LiPo is selected as the battery type. If time is not critical a charge rate lower than 1C may help to extend cell life slightly.

The requirement not to exceed the safe upper voltage limit means that the charge rate must be reduced towards the end of charge. The consequence of this is that charging will take longer for any given charge rate, so for example charging an empty LiPo at 1C can take up to about 80 minutes. The exact time will depend on such factors including the charger's software, the resistance of the charge leads and the internal design of cells.

Although it's possible to force a battery to be charged above 1C, the increased charge current requires a higher charge voltage, raising the effective cell voltage during charging. The means that the cell's safe upper voltage limit will be reached at an earlier stage of charging, at which point charge current must be reduced, so unfortunately the use of a high charge current will bring less of a time saving than might be anticipated. Additionally, any time saved comes at a price of reduced charging safety and reduced pack life. In conclusion, we should always be guided by manufacturer's recommendations for charge rates, and should never exceed a charge rate of 1C unless it is specifically permitted.

Stopping charging early
It's not harmful to the cells to stop charging early, but beware if you change your mind and decide to resume charging ~ the notes below explain why.

Charging part-charged batteries
Please use great caution if you decide to charge packs which are already nearly fully charged. Chargers which incorporate an automatic LiPo cell count may not correctly detect the number of cells in a pack. This could of course lead to overcharging. As an example, a charger could incorrectly identify a nearly charged 3S battery as a discharged 4S battery (The battery voltage would be around 12V in both cases). The charger would then begin charging the 3S pack as though it was charging a 4S pack, and the cells would soon become overcharged with the associated risk of fire. The greater the series cell count, the more likely this problem is to occur due to the increasing voltage difference between the charged and discharged states. Avoiding the use of an auto cell-count charger will prevent this problem from ever occurring, as would using a charge-through balancer.

Top-up charges
Topping up previously charged LiPo batteries is unnecessary and not recommended since they enjoy such a low self-discharge rate.

Relationship between internal resistance and charge time
The higher the internal resistance of a cell, the higher the charge voltage must be for any given charge rate, and the earlier on in the charge process the constant voltage phase will be reached, during which the charge current will have to be reduced. This means that a battery of high internal resistance will take slightly longer to charge than one of low internal resistance, even with the same charge rate selected. This factor is becoming less and less significant as modern high quality cells generally enjoy a relatively low internal resistance.

A simple reminder
Some modellers like to keep an elastic band around a charged battery pack as a reminder that it has been charged. This simple idea helps to avoid confusion between charged and uncharged batteries. A simple colour coding system can be used, for example red to indicate fully charged packs, and green for packs charged to a lower voltage for storage.

Internal cell pressure during charging

LiPo batteries are not fitted with a pressure relief valve, unlike NiMH types. When a LiPo cell is recharged, its internal pressure will gently rise, particularly as it approaches a fully charged state. Provided the cell is not overcharged the pressure will remain low and the cell will not become deformed. However, if it's overcharged, a LiPo will swell or 'puff up' and if the overcharging is continued, it will eventually explode.

Cell temperature during charging

LiPo batteries should never become warm during charging. If this does happen stop charging immediately and move them to a safe outside location and wait for at least 20 minutes. Don't charge a very warm battery (e.g. just after it has been used in a high current application) - allow it to cool off before recharging. A separate cooling fan may be used for this purpose. It's fine to charge batteries if they are only very slightly warm to the touch following a flight.

Never attempt to charge a LiPo if it is cold

Never attempt to charge a LiPo battery if it is close to, or below freezing (0°C/32°F). This is because crystals can form in the electrolyte at low temperatures and can result in an explosion if the battery is charged in this condition. Most manufacturers don't recommend charging below 10°C/50°F

Checking charge quantity

Many chargers will display the amount of energy/charge quantity supplied to a battery. Once charging is complete, it's always a good idea to compare the actual amount with the expected amount. This practice will help you assess an idea of the condition of the battery as it accumulates more use. It will also allow you to ensure that you are not habitually fully discharging cells in use, a practice that will shorten the life of batteries.

Remove batteries from models before charging

It's not recommended to charge a LiPo battery within a model because if a fire does occur, you will lose not only the battery but the entire model along with all its expensive equipment. Also because models are made from highly combustible materials they will only serve to increase the severity of any fire.

New cells - first charges

There is some evidence that new cells will benefit from being 'broken in' over the first few cycles, by charging and discharging them gently. The possible benefits of breaking in cells are probably greatest for high current applications such as high performance electric ducted fan (EDF) and 3D types. For low current models there is much less of a need to consider this issue. A possible running in schedule is shown in the table below:

Charge no:	1 (initial)	2	3
Charge rate	0.5C	0.75C	1C
Discharge rate following charge	Gentle	Moderate	As required

To achieve a reduced initial discharge rate, a model can simply be flown gently for the first couple of flights, perhaps with a smaller prop than usual. Alternatively, a securely grounded model could be used for discharging. If you do this, keep your distance while the prop is running and stop the motor at intervals to check that all of the power system components are adequately cooled. Electronic Speed Controllers (ESCs) may not receive enough cooling if located inside a fuselage and operated at low power for an extended period. Remember not to fully discharge cells. One highly respected manufacturer reported that 'post-mortems' on used cells confirmed the benefit of running in new packs. Those that had immediately been pressed in to hard use from new tended to be in poor condition and suffer a short life.

Flight testing new LiPo cells

Because of their high capacity and the possibility for long flight times, the power systems of LiPo powered models can develop unexpected overheating problems, even where no problem was previously found to exist using a different battery type. For this reason, it may be wise to limit the first flight to just a few minutes, after which the motor, battery and ESC may be inspected. If all is well, flight times and power levels may be extended. This practice will help to give advance warning of any overheating problems and is also kind to new batteries.

Check your charger before charging

If you have more than one battery type, for example a 2 cell and a 3 cell pack it is very easy to accidentally set your charger for an incorrect cell count. You may find it helpful to clearly label each of your batteries with cell count and capacity, and check very carefully that the charger has been correctly set before each charge. Also, if using a charger with automatic cell count detection, be careful to always ensure that it correctly assesses the number of cells being charged all through the charge process. Remember that most LiPo accidents happen during charging. A good motto is:

Check, check again, *then* charge.

Why can't a Nicad slow charger be used for LiPo packs?

Conventional slow charging, as used with nickel-based cells, involves passing a small current through cells for an extended period of time. This technique pays no particular regard to cell voltage and so cannot be used for LiPo batteries which are voltage-critical.

Charger power

All chargers have a limit to their charging power output. Remembering that Power = Volts x Amps, this power limitation means that for any given battery voltage, only a certain maximum charge current will be possible. The greater the voltage of the battery, the lower this maximum current will be.

For example, suppose you had a 50W charger. This would cope very well with 3-cell batteries, being able to charge packs at up to about 3.9A. This would make the charger suitable for charging 3-cell packs of up to about 3,900mAh in capacity at 1C. However, if you wanted to charge a 6-cell 5,000mAh battery using the same 50W charger the maximum charge current would be only 1.9A. This is a charge current of a lot less than 1C for this pack and so charging would take much longer than an hour. To charge this pack at 1C would require a charger with about 150W of charge power capability. The table below illustrates:

		Maximum charger power			
No. of cells	**Max on charge voltage**	**50W**	**100W**	**150W**	**200W**
1	4.2V	11.9 A	23.8 A	35.7 A	47.6 A
2	8.4V	5.9 A	11.9 A	17.8 A	23.8 A
3	12.6V	3.9 A	7.9 A	11.9 A	15.8 A
4	16.8V	2.9 A	5.8 A	8.9 A	11.9 A
5	21.0V	2.3 A	4.7 A	7.1 A	9.5 A
6	25.2V	1.9 A	3.9 A	5.9 A	7.9 A

NB These figures represent the maximum theoretical charge current for a variety of cell voltages and charger power combinations. In practice, the maximum charge current is likely to be roughly 5-10% less than shown, depending on the design of the charger.

By the same token, chargers are also similarly limited in their discharge power. A charger that has a 20W discharge power limit could discharge a 3 cell LiPo at about 1.6A, but it could only achieve 0.8A if working with a 6 cell battery.

Charge current requirement for charging more than 3 cell packs

Many chargers operating from 12V lead acid batteries incorporate internal voltage increasing circuitry. This means that when charging a battery with more than cells a current greater than the charge current will be taken from the lead acid battery. For example, when charging a 6 cell pack (with an on charge voltage of approximately 24V) at 2A, a little over 4A will be taken from the lead acid supply battery.

Chapter 8: LiPo batteries under discharge

What is the minimum safe voltage?
To recap, it is vital that cells are not discharged below their absolute minimum safe voltage. Manufacturers almost always specify this as being 3.0Vpc off load. It's worth noting that in the days of low performance high resistance cells, 2.5Vpc was a common figure. Today, cells of an ever higher performance with an associated lower resistance are being offered. In time, 3.0V may come to seem an unusually low minimum figure. For maximum cell life, it's already well worth considering using a slightly higher figure (3.3Vpc) and this is discussed in a later chapter.

ESCs and minimum voltage
It's important to make certain that your ESC is set for a cut-off voltage of at least 3.0Vpc. If you would like to increase battery life, then its worth considering using a higher minimum voltage than 3.0Vpc. The higher the quality of the cells, the more this is worth considering. This also is discussed later in the guide.

Use of a non LiPo compatible ESC
It is possible (but unwise) to use a non LiPo compatible ESC with LiPo batteries. The danger in so doing is that the ESC may allow your LiPo to become discharged below 3.0Vpc. This can be addressed by carefully timing flights. However, it's very easy to miss an audible time warning while flying a model, especially if a distraction occurs. Another complicating factor reducing safety margins is that actual cell capacity can reduce sharply with use so cells may be inadvertently over-discharged. By far the safest policy is only to use LiPo compatible ESCs with your LiPo batteries.

If batteries are over discharged
A single occurrence of a very slight over discharge is unlikely to have a significant effect on a battery. However, damage is cumulative and cannot be reversed so if cells are frequently over discharged, and/or have been deeply discharged, the pack will have been permanently damaged. On recharging, cells could swell up so the charging process will need to be very carefully monitored.

After a deep discharge episode the weakest cell in the pack may well have been damaged to a greater extent than the others, increasing any tendency for the pack to become unbalanced. The safest advice is to discard a pack that has been over discharged. If you choose to keep such a pack in service treat it with suspicion and remember its history.

Discharge rate and battery capacity
The rate at which a battery is discharged will affect the available capacity ~ the faster it's discharged, the lower recovered capacity will be. This is because at high currents more energy is lost in the form of heat within the cells, so less energy is available for the motor. LiPo capacity is normally specified as the capacity delivered at a relatively low rate e.g. over a period of 2 hours. In modelling applications, flight batteries are inevitably discharged at considerably higher rates than this, which may mean that in practice a significantly lower usable capacity is recovered than the stated quantity, especially as they accumulate usage.

Self-discharge rate
A healthy LiPo battery may be expected to hold its charge without significant loss for many weeks or even months. This contrasts strongly with nickel-based cells, which have much greater self-discharge rates.

Battery performance and the effects of temperature
Chemical reactions tend to be accelerated at raised temperatures. Batteries, being essentially chemical devices will also be affected by temperature. The resistance of a LiPo is significantly less when it is warm. This is why slightly warm batteries will tend to maintain a higher on-load voltage compared to cold ones. However, although warm cells are generally preferable to cold ones, it does not follow that hot cells are even better ~ it is very important never to allow cells to become hot for reasons of safety and of course lifespan.

Excessive discharge rates.
In general, the lower the discharge current, the longer the lifespan of batteries will be. Batteries should never be discharged at a higher current than the maximum recommended because they will probably become excessively hot, quite possibly suffering internal damage and even catching fire. Model performance will also be poor if using unsuitable batteries and the connecting tags between cells may also become hot.

Furthermore, although a battery may be able to maintain an excessive rate of discharge for a while, eventually its voltage will tend to collapse well before it is actually exhausted. (This is probably due to the limit of the speed of the chemical processes within the cell being reached.) Batteries operated at extremely high discharge currents tend to have short lives, perhaps only ten or twenty cycles. An ammeter will prove to be very useful to ensure excessive discharge currents are not occurring.

In addition to the cell manufacturer's instructions, the battery's temperature in use serves as a reliable guide as to the discharge current – if adequate ventilation is provided yet the pack becomes hot it is definitely being discharged at an excessive current. It is of course far better to avoid this situation by checking the discharge current before flying.

Keeping batteries cool
Some ventilation must be provided for motor batteries to prevent cell temperatures becoming too high. Some manufacturers assemble packs with a gap between each cell to encourage ventilation.

If your batteries are becoming too hot, either take steps to reduce the current drawn by the motor or change the battery for one with a higher capacity and/or higher C rating. Motor current may be reduced by one or more of the following:

- Reduce the diameter and/or pitch of the propeller.
- If a gearbox is fitted, increase the gearbox ratio (for example from 3:1 to 3½ :1).
- Reduce the cell count.

Discharge time and its relationship with C
The relationship between the time to discharge a battery and the equivalent C rating is not often appreciated. The table below shows how long a cell will take to become fully discharged at various discharge currents, expressed in terms of C. Remember the table applies to a battery of any capacity and voltage:

Discharge rate:	1C	5C	10C	15C	20C	30C	35C	40C
Time to discharge:	60min	12min	6min	4min	3min	2min	1.7min	1.5min

As we would expect, discharging at 1C takes one hour (e.g. a discharge at 2.5A for a 2,500mAh battery). Similarly, 30 min will be required to flatten a battery at 2C (5A for the same pack) and at 10C a battery will be exhausted in only 6min. Similarly, we can say that if a battery provides a flight time of 4 min. it must be being discharged at 15C.

Referring to the table above shows clearly that flight time will be unacceptably short if a battery is discharged at a high C rating, even if the resulting current is within the battery's capabilities. Also, battery lifespan will be enhanced if moderate discharge currents are used.

Burst ratings
Some batteries are rated for a short term increased current capability. For example, a battery might be rated for 20A continuous, with bursts of 30A. Short term or burst ratings are really intended only for competition flyers who have little interest in battery lifespan. For sport modelling use, burst ratings are best ignored.

Chapter 9: Balancing matters

The cells of an ideal battery would all have exactly the same capacity and would behave identically. However, in practice there will always be small variations between individual cells; they will for example each have slightly different capacities, different rates of self discharge, differing internal resistance and so on. These differences particularly apply to LiPo cells, which are reported to be more difficult to make to a consistent quality compared to other cell types.

The cells within a new battery may be expected in virtually identical states of charge. If the battery is then stored, or used without balancing equipment they will come to be in unequal states of charge. Whatever the reason, a battery in this state is said to be 'unbalanced'. A battery in a severely unbalanced condition is potentially dangerous and its cells must be balanced before it is used again. Let's have a look at the problems of using an unbalanced battery:

Charging unbalanced series connected cells

Let's consider the example of a severely unbalanced 3S battery in a low state of charge. Before charging, we'll assume that one cell starts out at 3.0V, one at 3.1V and one at 3.2V. For simplicity, we will also assume that this 0.1V difference between each cell will be maintained in all states of charge. All of the cells will start to rise in voltage as charging begins. At some point, the cell voltages will be 4.0, 4.1 and 4.2V, meaning the voltage of the whole battery will be 12.3V. The cell at 4.2V is now already fully charged. However, the charger would not be able to detect this, and so it will continue charging until the battery voltage has risen to 12.6V.

This means that the cell which is already at 4.2V will become overcharged; by the time the battery has reached 12.6V, the cells will be at 4.1, 4.2 and 4.3V respectively. The most serious problem with this battery is the cell now at 4.3V, which has of course been overcharged, with the attendant risks of damage and even fire.

This risk of overcharging unbalanced batteries is one reason why some chargers use conservative maximum voltages, for example 12.45V may be used for a 3 cell battery. In this example, the cells would reach 4.05, 4.15 and 4.25V; one cell would still be overcharged, but by a smaller margin.

Discharging an unbalanced battery.

Let's now consider this same battery under discharge conditions. At some point the cells will again be at 3.0, 3.1 and 3.2V. If this battery were to be further discharged to a 'safe' value of 9.0V, this will clearly only happen when the cells have reached 2.9, 3.0 and 3.1V respectively. One cell will therefore have become over-discharged and possibly damaged.

Balancing equipment

In the examples above all charging and discharging occurred through the main power leads, so balancing of individual cells wasn't possible. Modern packs have an additional multi-pin connector which allows electrical access to each of the cells individually. This is called a charge/balance connector. For convenience, we will abbreviate this to balance connector.

Charge/balance connector
Charge balance connectors are fitted to all good quality LiPo packs. They allow electrical access to each individual cell. Charging occurs through this connector (except if using a charge through balancer) and allows each cell to be kept in balance with its neighbour. Discharging is via the pack's main power leads.

Usually, the cells are charged through the balance connector, and the main power leads are usually used only for discharging. During charging, if required a small load is simultaneously applied to any cell which has a higher voltage than the lowest one (except balance chargers). This process keeps all cells in balance during charging. The thin wires used for balance leads means they have a limited current carrying capability. Charge currents of up to around 2A or so are safely possible. Devices to carry out this function are called 'cell balancers' and are easily available. They connect between the charger and the battery. Always make sure you have a suitable balancer when buying new batteries as their use is not really optional if safety is a consideration. It's also worth checking the type of balance connector when buying LiPo packs to ensure that it's compatible with any existing equipment you may own. Failing this, conversion leads are usually available. The different types of balancers are outlined next.

High rate charge through balancers

A high rate charge through balancer such as Flight Power's V-Balance allows cells to be charged through the pack's main power leads, while the cells are simultaneously monitored and balanced via the balance connector. Since the charge current passes through the main power leads, higher charge currents are safely possible than if the balance lead were used. This issue is becoming ever more relevant as high capacity packs become more common. For a pack of say 5,000mAh a 1C charge current would be 5A, which is far too much to pass through a charge/balance lead. The best quality charge through balancers will also be able to stop charging or discharging if a problem is detected.

Charge through balancer

Flight Power's V-Balance is a microprocessor controlled, high rate charge through balancer. A high quality charge through balancer probably provides the best available protection during charging for cells and operator.

Simple balancer

This is an in-line or charge through device. It is located between the charger and the battery. Cells are charged through their balance connector and a small corrective current is simultaneously applied to any cell which becomes out of balance.

Simple voltage limiter

There is at least one so called balancer which, instead of being a true balancer simply applies a discharge current to any cell which exceeds 4.0Vpc. Such a device offers a lot more protection than nothing, but its operation does not constitute true balancing. It's worth checking the actual operation of a cheap balancer you may be considering.

Balance chargers

Balance chargers accomplish cell balancing by charging each cell separately rather than by applying a load to individual cells. One possible disadvantage of this type is that the charger output is via an unchangeable connector. If you are happy to be tied to one manufacturer's equipment (or if conversion leads are available to connect to other makes of battery) they can be worth considering.

Balance charger

An example of a balance charger. The output on this example is via the row of white charge/balance sockets along the front.

Limitations of balancers

Balancers are necessary for safe charging. Although recommended, they are not a substitute for proper charge practices and it shouldn't be assumed that their use guarantees safe charging. Also note that balancers don't necessarily ensure that cells will behave perfectly - a faulty pack will be bad whether or not a balancer is used.

It's worth remembering that balancers, like any piece of equipment can occasionally go wrong, so an apparent battery problem may in fact be to do with something else. If in spite of using a balancer a battery problem is suspected, it just might be the balancer itself that's the problem.

Charging LiPo batteries without balancing equipment

A good quality pack in good condition should be able to provide many flights without becoming significantly unbalanced. However, this cannot be guaranteed and so it's safest to ensure that cells are balanced at least every few cycles. The best policy of course is to use a balancer for every charge, especially if it's an intelligent type which is able to independently halt the charge process if a problem is detected.

The risks of charging without the use of balancing equipment are highest with older or lower quality packs as these are more likely to have developed a problem. Remember that the cells in an unbalanced battery pack are at greatest risk when they are close to fully discharged *and* when close to fully charged. It's therefore a good idea not to fully discharge or fully charge a potentially unbalanced pack without using a balancer.

The continued use of unbalanced cells will lead to one or more of them becoming over charged and/or over discharged with each cycle. This is the reason why a battery that has previously performed faultlessly 'unexpectedly' catches fire. If you have a well-used battery that has never been balanced it would be wise to stop using it until it has been balanced.

Older packs without balancing leads

Older LiPo packs that are not fitted with a balance lead must be used with caution, and for safety should be assumed to be potentially unbalanced. As long as the pack appears sound and is not fully charged or discharged it may be kept in service. It would be wise not to fully charge or discharge such a pack, just in case one of the cells falls outside the safe voltage range.

Disposal of LiPo batteries

A commonly recommended procedure for the disposal of LiPo batteries is to discharge the cells, puncture their cases with a sharp object and place them in salt water for a few days. The problems here are firstly that puncturing the cells brings a risk of exposure to toxic chemicals, and secondly that the objects used for this procedure will become permanently contaminated by contact with the cell's interior. If they happen to be household objects such as knives, screwdrivers or drinking glasses you could unknowingly later become poisoned. This method of disposal is therefore not recommended, due to the risk of exposure to any of the toxic materials by breaching the outer casing in any way.

The safest advice is to take the cells outside and then fully discharge them slowly down to close to zero Vpc (perhaps using a car bulb) so they no longer represent a significant fire risk, and then take them to a suitable recycling centre, clearly labelled as to what they are.

Chapter 10: Getting the best from LiPo cells

Avoiding over working batteries
To ensure that packs don't wear out prematurely it's important to make sure they are not regularly too deeply discharged or over worked in terms of the discharge current. This issue is not quite as straightforward as simply keeping the discharge current within the labelled rating.

Over optimistically C rated batteries
LiPo cells will return a longer lifespan if used well within their rated capability. It's worth knowing that some LiPo batteries are more optimistically rated than their performance would suggest is appropriate. This applies mostly to cheaper packs. Such packs may therefore suffer excessive harmful internal heating even when used within their maximum rated current. Cases are known where cheap packs only lasted one or two flights when used at (but not above) their maximum rated current.

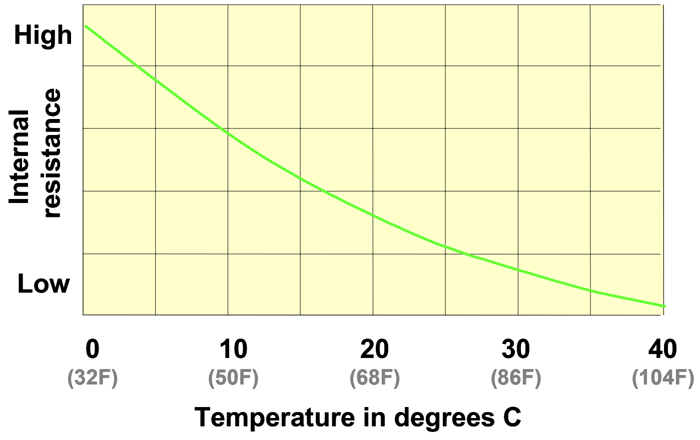
For all packs, especially cheaper ones, if maximum lifespan is required it is worth considering using them at a more conservative value. Restricting the maximum discharge current to no more than 2/3 of the rated value should allow for all but the worst examples of over optimistically rated packs. This will also help to increase the lifespan of correctly rated packs. For example for a pack rated at 20C, perhaps consider employing it in service at not more than 13C. Many sport model power systems are operated at moderate power levels and so this issue is often taken care of without making special precautions. The table below makes a handy reference:

Pack rating	10C	15C	20C	25C	30C
2/3 of pack rating	7C	10C	13C	17C	20C

Applying this idea will also help to ensure that you get a good flight time. Also, by restricting the current value to ⅔ of the rated value, only about half the heat will be generated as would be at the full rated current, so the chance of damage caused by internally generated heat is much reduced.

Internal resistance and temperature
LiPo cells have a significantly lower internal resistance at high temperature than at low temperature. This is the reason that cold cells don't perform as well as warm ones. The graph below illustrates the relationship between a battery's temperature and its resistance:

Relationship between
Internal Resistance & Cell Temperature

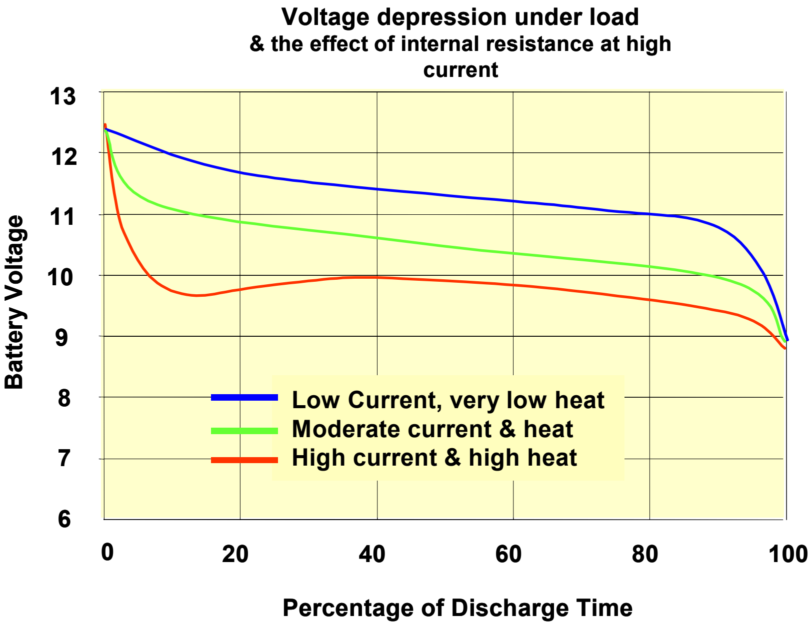


Battery temperature
The effect of low temperature on LiPo batteries is easily demonstrated on cold days. If a cold pack is put into a model requiring a medium to high current, the model's performance might well be noticeably worse at the beginning of the flight than it would be with a warmer pack. Flying with cold packs is roughly equivalent to using them at a higher discharge current at a

warmer temperature. Consequently, using packs at high currents when they are cold may cause them harm, and to avoid this possibility and to ensure good performance it's worth keeping them in a warm place until they are required for use.

Heating effects during a high discharge current

The issue of the cell's internal resistance is of particular relevance when using cells at high power levels, as an additional factor comes into play. At high discharge currents, the heat generated within the cell as a result of its own resistance will be sufficient to cause its resistance to fall as the discharge progresses. If the current is high enough, the effect can be that the on-load voltage will actually rise for a time, even though the battery is being discharged. The explanation for this phenomenon is that the fall in resistance is more than making up for the reduction in the battery's state of charge. The graph below illustrates this effect:



At low and moderate currents (blue and green lines) the heat generated is not sufficient to significantly lower the cell's internal resistance, and the on-load voltage declines throughout the discharge process. However at a high current (red line) the on-load voltage is seen to start to increase as the cell approaches 20% of the discharge time. This effect may be termed a 'swan neck' due to the shape of the graph.

If maximum power is your objective then clearly this effect will be considered to be a benefit. However, operating packs at the edge of their performance envelope will come at the price of a reduced battery life so it's best to avoid discharge currents that are high enough to cause this effect if you hope for a long life from your LiPo. Remember that the inside of the cell will be even hotter than the exterior surface. If you see this effect in action, it may be taken as an indication that the cell is possibly being worked too hard to enjoy a long life. Practically, you can test for the effect by discharging a battery with a voltmeter connected; if the voltage is seen to climb after a while then it may be assumed that this is the reason why.

Reducing the current

To reduce the current, a smaller propeller can be used. An alternative is to maintain the discharge current but to use higher C rated batteries and/or higher capacity batteries - the same current for a larger battery will represents a lower value in terms of C. For example, the table below shows that a current of 60A represents 20C for a 3,000mAh pack but the same current is only 15C for a 4,000mAh alternative:

Cell capacity:	**3,000mAh**	**3,300mAh**	**3,600mAh**	**4,000mAh**
Equivalent C rating for a current of 60A	20C	18.2C	16.7C	15C

Extending the life of cells: Preferred voltage range

We've already seen that the absolute safe voltage range for LiPo batteries is 3.0Vpc to 4.20Vpc. Maintaining packs within this range will ensure that they are operated safely and also allow the maximum charge quantity to be utilised. However, deterioration of the cells will be accelerated during periods that the cells are held at or near to these voltage limits. To allow the batteries to enjoy an increased cell lifespan, a slightly narrower voltage range is therefore preferred. There's some evidence that high capacity packs will particularly benefit from this advice.

Preferred minimum voltage

The preferred minimum voltage is slightly higher at 3.3Vpc. Adopting this higher voltage results in only a small proportion of the battery's maximum charge quantity remaining unused and will extend the life of packs.

Preferred maximum voltage

Although not unsafe, charging all the way to 4.2Vpc will promote accelerated deterioration if they are then stored fully charged. If you have been in the habit of fully charging your battery after use ready for next time, this means that your battery will be spending almost all their life stored at 4.2Vpc, which is far from ideal. There's no problem with charging packs right up to 4.2Vpc if they are used soon afterwards, but if the battery isn't needed right away then a better charge decision can be made. There is some evidence that charging only to say 4.1Vpc prior to use might help to extend battery life, although this will mean some capacity remains unused.

If extended storage (longer than a few days) is intended then 3.8 – 3.9Vpc is an ideal voltage target, equivalent to about a 60% state of charge. This is most easily achieved if your charger is able to be set to supply a suitable maximum charge quantity. Alternatively packs can be fully charged and then discharged by a set amount. One reason that new LiPo cells are always supplied in a part charged state is to avoid any unnecessary deterioration.

The table below makes a handy reference for 1-6 cell packs in an off-load condition.

	Low level		Nominal	Storage	High level
No. of cells	Safe absolute minimum: 3.0 Vpc	Minimum for extended life: 3.3Vpc	Nominal voltage: 3.7Vpc	Ideal: 3.8 – 3.9 Vpc	Safe maximum: 4.2Vpc
1	3.0	3.3	3.7	3.8 – 3.9	4.2
2	6.0	6.6	7.4	7.6 – 7.8	8.4
3	9.0	9.9	11.1	11.4 – 11.7	12.6
4	12.0	13.2	14.8	15.2 – 15.6	16.8
5	15.0	16.5	18.5	19.0 – 19.5	21.0
6	18.0	19.8	22.2	22.8 – 23.4	25.2

Buying new LiPo Batteries

There's a great deal of choice when it comes to LiPo batteries. The following discussion is intended to help you make well informed choices.

C rating

Some manufacturers heavily promote the C rating of their cells, which can lead to modellers assuming that higher is always better regardless of the application. Having some capability in reserve is a good thing, but there's certainly no need to buy cells with the highest available C rating; provided that the C rating of cells is sufficient for your purpose they should be satisfactory. A pack discharged at 30C will be flat within 2 min – and very few modellers have a requirement to discharge cells even half as quickly as that.

Cheap cells
The temptation exists to try and save money by purchasing cheap batteries. However, as with all products, you almost always only get the quality that you pay for – cheap doesn't necessarily mean good value. Cheap cells tend not to hold their voltage well under load, resulting in poor model performance. A little research will probably help you discover the sort of experience that others have gained with a particular make of battery, for which the internet can be very useful.

> *"There is hardly anything in the world that some man cannot make a little worse and sell a little cheaper, and the people who consider price only are this man's lawful prey."*
>
> John Ruskin, 1819 - 1900

It's possible that a cheap LiPo might work out well in a relatively undemanding application, with it giving no problems for many cycles. However it's more likely that a cheap pack will turn out to be poor value for money, perhaps only giving a short service life especially if higher discharge currents are demanded. High quality packs are more likely to last well and also more likely to come with high quality after sales service, such as a willingness to replace a faulty pack. Try to strike a balance between quality and price that will work best for you.

Claimed C rating
It's not unknown for packs, especially those of lesser quality to be over-rated in terms of their current capability, or C rating. Again, a little research can be useful. If you do wish to buy cheap packs, it's probably worth assuming that they are over-rated and accordingly allow for this.

Deciding on capacity
Skimping on capacity is never wise, unless weight is absolutely critical. Surprisingly, it could actually be cost effective to buy a slightly larger pack than it may appear you need. If a battery of generous capacity is chosen, four main benefits result:

a) Flight duration will be longer.
b) The discharge current is effectively reduced in terms of 'C', giving the pack an easier life and thus increasing the chance of it lasting well.
c) The model's performance is likely to be a little better, even allowing for a slightly increased battery weight, as the battery voltage will be greater for the same load, and hence provide more power.
d) Higher capacity cells may be charged at higher currents. Therefore, a given charge quantity may be added to the battery more quickly.

Although larger packs will weigh more, with LiPo cells the additional weight is not usually a significant factor for most models. However one significant disadvantage of larger packs is that a greater investment is tied up in one battery so there's a bit more at risk in the event of a crash.

High cell count packs
Large LiPo packs represent a substantial investment. If for example you needed a 6S 3,700mAh pack for a large model, it may be worth considering purchasing two 3S 3,700mAh packs, which would be dedicated to that model and used in series. In this way, if damage occurred to one of the packs, at least one would still be able to use the other pack in a smaller model, thus retaining some of the value of your investment.

Balance connector
All good quality packs will be supplied with a balance connector. I would strongly advise against purchasing a pack without such a connector, as this makes it impossible to keep the cells balanced. Also refrain from purchasing any battery for which you cannot obtain a suitable balancing lead.

Safe ways to reduce the required charge time

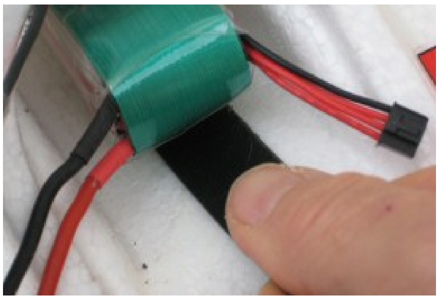
There are several options available to minimise the inconvenience of having to wait for more than an hour for your LiPo batteries to charge. These are discussed below:

- Don't flatten cells completely. Naturally, a considerably shorter period will be required for charging if they don't start from a fully discharged condition. Plus, the life of your pack will be extended.

- Have more than one pack available. One pack can be charging while another is being flown. Two chargers will still be required in most cases. Three packs and two chargers is another possibility. Because LiPo cells hold their charge so well, multiple packs can be brought to a flying session charged up ready for use.

- Choose larger cells for a model. Since the 1C charge current is higher for larger batteries than smaller ones, the use of larger packs will allow a given charge quantity to be added to a pack more quickly.

- Stop charging early. Charging can be stopped early, perhaps at the point when the constant voltage part of the charge process is entered. By this time, the pack will already be approximately 85% or more charged. If maximum flight time is not required this can yield a useful time saving. (The charge process graph shows that the last 15% of charge quantity takes nearly a quarter of the total charge time. The final 5 min of charging adds an almost insignificant further charge quantity). The 15% unused capacity can easily be compensated for by choosing a slightly larger battery. Avoiding taking the pack all the way up to 4.2Vpc will help to extend pack life slightly.



Extracting batteries fixed with Velcro

When extracting a battery from a model that's held in position by a hook and loop tape such as Velcro, there is a danger that the necessary force could cause the cell's Mylar case to be pulled away from the cell's internals, damaging the battery.

A removal device consisting of a piece of thin plastic card forms a simple solution to this problem – the card is inserted into the gap and is used to prise apart the hook and loop tape . Take care not to pull the battery by its wires

Electronic Speed Controllers (ESC)

The ESC's performance can have a significant effect on battery lifespan. From the battery's point of view, the main area of interest is their behaviour as its cells become fully discharged. All ESCs have a power cut off (PCO) feature (also known as a low voltage cut-off, or LVC), which interrupts power to the motor when battery voltage becomes low. This feature serves both to protect the cells from becoming excessively discharged and also ensures that a reserve of energy exists to power the receiver and servos. For best battery lifespan, ideally we should stop flying before the PCO feature operates. Many pilots time their flights for this purpose.

Many ESCs also offer several options as to how the PCO function can be set up. Common options are a 'soft' cut off, in which power is gradually reduced in response to low battery voltage, or 'hard' where the power to the motor is abruptly terminated. One idea worth considering for sport models is to have the ESC set for a relatively high cut off voltage (e.g. 3.3Vpc) combined with a 'soft' cut off. In this way battery receives a high level of protection, and the safety of the model is ensured as power will not suddenly be cut.

Older ESCs

Note that the PCO function of some older LiPo compatible ESCs will allow cells to discharge to around 2.5V which is too low for modern cells. If being used with modern cells, such an ESC is best treated as though it were a non-LiPo compatible type.

Using LiPo cells as a power source for the RC system

The advantages of LiPo cells means they are now increasingly used as a source of power for RC equipment, usually in conjunction with a separate voltage regulator (such as a SBEC or UBEC) designed for use with LiPo packs. In this safety critical application, make sure that high quality cells are used. For maximum reliability it's well worth housing the batteries in a padded environment (e.g. a foam lined battery compartment) for protection against vibration and landing shocks, and also ensuring that the regulator is suitably mounted and that its wires are not vulnerable to breakage. Balance props carefully to minimise airframe vibration and remember always to remove LiPo batteries from the model as soon as flying is over and for charging.

Remove batteries straight away after flying

Remember always to remove a LiPo from a model after flying because many ESCs will draw a current from the battery even with the switch in the off position. If you have a voltage monitor, this too will place a small load on the battery. The only way to be sure that your battery is not slowly being discharged is to remove it from the model. Many people have ruined batteries by leaving them in a model, incorrectly believing that no current was flowing from it.

Soldering connectors

When soldering connectors to new LiPo pack power wires, try to ensure that as little heat as possible migrates along the power leads to the cells. A hot, clean iron applied for the minimum time to clean joints is the best way to ensure that the minimum of heat is applied.

Charge bags

LiPo batteries should always be frequently monitored during charging. In practice many of us fail to do this. With this in mind, a fireproof LiPo charge bag may be a worthwhile investment.

The pack under charge is placed within the bag, and should the worst happen it will absorb some of the force of any fire and will contain the debris. The disadvantage of such bags is that the pack cannot easily be observed during charging – perhaps a small price if the pack is not going to be kept under frequent observation anyway.

Cooling of cells in cold weather

The cooling arrangements on a model which work well on a summer's day may be providing an excessive supply of cooling air in winter. When flying in cold weather, its worth considering reducing the cooling intake area if this is the case. Be careful not to restrict the intake area too much, and remember to remove any such restriction before flying in warmer weather.

Chapter 11: Checking and testing LiPo batteries

From time to time it may be useful to be able to check on the condition of a LiPo battery. In particular, we may want to check the voltage of each of the cells. Such times include:

- Before first charging a new battery (manufacturer's instructions often advise this)
- When using a battery that's been in storage.
- At the first suspicion of a problem with a battery, charger or balancer.
- Routine checking of cell balance to ensure that there are no severely unbalanced cells.

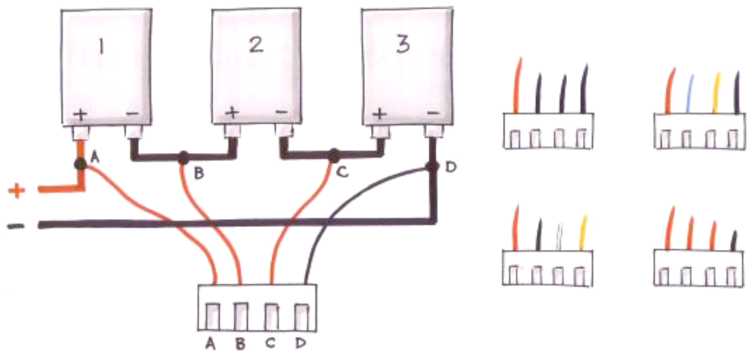
We may also want to assess other performance parameters such as actual capacity. To accomplish this, useful test equipment includes a microprocessor-controlled charger/discharger (cycler) or other device such as a wattmeter able to record the battery's capacity along with a methodical system of recording results. None of these techniques involve any disassembly of the battery. Disassembly is not recommended unless you are sure you are competent to take this work on.

NB Fully discharging LiPo batteries should be at most an occasional practice as taking cells to a fully discharged condition is detrimental to their health. It's advisable not to leave the battery in a fully discharged state for long, so arrange to recharge it again straight away.

Before working on a battery
Before working on a battery, first check its physical condition. Inspect it for any loose wires, dirty connectors, skin punctures, dents, puffed or swollen cells, damaged insulation etc. Always inspect a pack carefully that has been crashed. Batteries are relatively fragile and any serious internal damage could cause a short circuit which might lead to a fire.

Checking individual cell voltages
The balance connector exists to allow electrical access to individual cells, and represents the easiest way for us to measure their voltage. Due to the lack of an agreed industry standard, there are several balance connector designs in use. For all designs the connector will always have one more wire than there are cells. For example, a 2 cell pack will have a 3 wire connector; a 3 cell pack will have a 4 wire connector and so on.

Balance connector wiring
The diagram below shows the wiring connections for a 3 cell LiPo pack. The three cells are connected in series, and the balance connector wires attach to each cell tab. The same general principle applies to other pack sizes. The thick lines represent main power wires. The thin lines represent the balance connector wires, and by using (in this example) 4 wires we can access the + and – connections of each of the three cells. This allows us to measure the voltage of cell 1 by placing the probes of a voltmeter between points A and B of the charge balance connector. Similarly the voltage of cell 2 is found between points B and C, and cell 3 between points C and D.



Wiring colours

The diagram above also illustrates a number of alternative wiring colours commonly used for balance connector wiring. The actual colours are unimportant, in every case cell voltage can be measured across adjacent connections.

To measure cell voltages

Voltage checks can be done using the voltmeter function of a simple inexpensive digital multimeter. Analogue meters (the sort with a moving pointer) cannot be read accurately enough so are of absolutely no use for checking the state of balance of a pack. To check cell voltages simply use your meter in the following way:

1. Check that the meter's leads are connected to the appropriate sockets: black in the negative (–ve) or common (COM) socket, red in the socket appropriate for measuring voltage. Note that many meters have a separate socket intended for measuring current up to 10A ~ if you use this one the battery will be short circuited. Don't use this socket!
2. Ensure the rotary function selector is set for an appropriate voltage range (e.g. 20V)
3. Preferably also ensure your probes are insulated except for the last 6mm (¼ inch). This precaution guards against an accidental short circuit.
4. The voltage of each cell may now be measured by placing the probes across adjacent connector contacts. You may like to record the voltage of each cell for future reference. NB. Always select the voltage range before connecting to the battery.

Multimeter

This digital multimeter is correctly set up to measure cell voltage. The rotary function selector switch is set to an appropriate voltage range, in this case 20V.

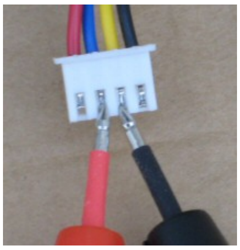
The probes are connected to the correct sockets for measuring voltage ~ the black probe is connected to the lower COM (common) socket, and the red probe is connected to the V socket.

The uppermost socket on this meter is used only for measuring high currents and must never be used when measuring voltage.

Checking cell voltages

Here, probes are seen used to measure the voltage of the individual cells in a pack. On the left, cell 1 is being measured (probes between A and B), and on the right cell 2 is being measured (probes between B and C).

It's worth insulating all but the very end of your probes with heat shrink tubing to minimise any risk of an accidental short circuit when checking cells.



Interpreting results

A battery may be considered to be balanced when its cells have a maximum difference of 0.02V (1/50V) from each other. It should be considered unbalanced if the difference is greater than this, and severely unbalanced if the difference reaches 0.05V (1/20V) or more. The following 3-cell examples illustrate this principle:

- Cells at 4.13, 4.13 & 4.15V. Voltage range = 0.02V. Battery balanced & safe to use.
- Cells at 3.98, 4.01 & 4.00V. Voltage range = 0.03V. Battery unbalanced.
- Cells at 3.95, 3.89 & 3.91V. Voltage range = 0.06V. Battery severely unbalanced.

If a battery is balanced, working well and undamaged then there is usually little point in carrying out further testing. In this case the best advice is to keep enjoying using it. However, if a battery is displaying signs of a problem then further testing may be required.

Cells above 4.20V

In a charged and balanced pack, no cells should be found above 4.20V. However if any cells are found above this voltage, they should be partially discharged to bring voltages down to 4.20V or below. Any apparent over voltage condition might be the result of an over-reading voltmeter. This is quite possible with a really cheap example. If this is suspected, have the meter checked and/or use another meter.

Note that very occasionally, some manufacturer’s chargers deliberately allow batteries to be charged to very slightly above 4.20Vpc (maybe as high as 4.25Vpc absolute maximum) to cram the maximum charge quantity into a pack. In this case the warnings about keeping cells in a fully charged state apply even more so.

Cycling of LiPo batteries

Cycling batteries serves no useful maintenance purpose, although it may of course be useful to know the capacity of a battery. Frequently cycling LiPo packs to a fully discharged condition is not a good idea because it reduces lifespan and introduces the possibility of one cell falling below 3.0Vpc, therefore damaging it.

For these reasons some chargers will not permit LiPo batteries to be discharged or cycled. If you still want to cycle a LiPo, it is recommended to use balancing equipment which has the ability to monitor cell voltages and which will stop the discharge process if an unsafe condition is approached. Flight Power’s V-Balance is one such device.

Choosing a suitable discharge rate for testing

Some LiPo tests involve discharging the pack. The industry standard discharge current used for capacity tests is 0.5C or less, but you may find it more convenient to use a value of 1C, requiring approximately one hour for discharge – that is, if your discharging equipment can achieve this rate of discharge.

Many chargers are in fact rather limited in their discharge power (20W being a common figure, equivalent to about 1.8A for a 3S LiPo or 1.4A for a 4S pack) so you may have to simply accept a current of less than 1C. This will create no problems apart from the time required.

No balance connector?

If your battery is not already fitted with a connector to gain electrical access to each individual cell, no checking will be possible without removing the cell’s covering, usually in the form of heat shrink insulation. Please be aware that this sort of work is potentially risky due, for example to the possibility of damaging the soft case of a cell, incorrectly identifying cell connections, inadvertently causing a short circuit etc. There is a certain difficulty here; in order to satisfy ourselves that a battery does not pose a risk to our safety, it’s necessary to carry out a procedure that is itself slightly risky!

Because of the risks, I strongly recommend that you do not work on battery packs unless you are both electrically experienced and absolutely confident of your ability not to cause short circuits or otherwise damage cells. Many modellers will not be in this position, and so the assistance of someone with the specialist skill and experience to do so will have to be found. If you do decide to work on a battery, you do so entirely at your own risk.

By carrying out such work, you will of course also invalidate any guarantee, although this might be a better option than continuing to use a potentially unbalanced battery. In places this guide discusses working on battery packs, but no implication is intended that it is safe to do so.

Testing for capacity

Starting with a fully charged and balanced battery, simply discharge it using a cycler and record the recovered charge quantity. The actual capacity of the pack may then be compared with its stated capacity. Some degradation of capacity should be expected in used cells.

A reasonable alternative to using a cycler is to discharge the battery gently in a model and then recharge it, noting the charge quantity restored to the cells. The losses due to charging inefficiency are relatively low with LiPo cells and may be discounted, so this method will still give a useful indication of capacity. The low and high voltage cut-off values used by a charger (or ESC if discharging in a model) will of course affect the apparent capacity of the cells, the more conservative these values, the lower the capacity will appear to be. Therefore, if a battery appears to be low on capacity, contributory factors could be that the charger is set to a conservative (safe) voltage value and/or the battery is not being fully discharged.

Self discharge rate

The self-discharge rate of healthy LiPo batteries is very low, perhaps 1-2% per week. The actual rate will depend on the cell’s type, condition and the storage temperature (lowest when cool). Batteries with a higher discharge rate than this are not necessarily unfit for service. If one cell within a battery has a significantly higher self discharge rate than the others, (indicating the possibility of a ‘soft’ or high resistance internal short circuit) it should be monitored carefully and be subject to frequent balancing.

The capacity of used cells

Modelling applications tend to place serious demands on our LiPo batteries, especially if high currents are required. Consequently, LiPo batteries will tend to lose capacity as they are used, generally to a far greater extent than for other cell types. The amount of loss will be affected by factors such as the severity of charge and discharge currents used, depth of discharge and cell quality. Capacity loss should be moderate if packs are of good quality and used with care, but it could be as high as 50% within only ten cycles in the very worst cases.

Interpreting test results

A battery delivering a reasonable capacity and with an acceptable self-discharge rate needs little comment. However if a battery test indicates a poor result, it’s worth first checking the settings of your charger/cycler. Even our fragile LiPo batteries are often more reliable than we humans! Note that unlike some other battery types, poorly performing cells cannot be recovered ~ unfortunately, any performance degradation will be permanent. Some possible problems are:

Battery appears to have a substantially reduced capacity

If a cycle test shows a battery to be very substantially below its stated capacity there are several possible explanations. The most likely explanation is that the battery is simply old or worn out.

If cycling a battery containing a bad cell (i.e. low on capacity/voltage) with an intelligent balancer this would stop the discharge process when one cell reached 3.0V and the recovered capacity would be reduced. In this case one bad cell will cause an entire battery to appear low on capacity.

Alternatively if a pack contains a bad cell (i.e. low on capacity/voltage) cycling through the battery’s power wires will result in that cell becoming over discharged. The recovered capacity may not be significantly affected but the cell will be damaged.

Pack has a high self-discharge rate

A battery suffering from a high self discharge rate may also have a severely reduced capacity. There’s nothing that can be done about cells in this condition.

Battery appears to be completely ‘dead’

If you suspect your battery is dead, the first thing to do is to measure the battery voltage across its main power wires. If this voltage is very low, the likelihood is that the pack has been seriously over discharged. In this case, it should be discarded.

In the unlikely event that the cell voltages measured at the balance connector are still healthy, the problem may lie with the power wire connector or the power wiring. In this case a repair should only be attempted by someone with the necessary skills and experience.

Cells with reduced capacity

If a new battery has been treated carefully and is suffering from unacceptably low capacity, it should be returned to the place of purchase for replacement. Used cells can of course be expected to have a reduced capacity.

Replacing individual cells

It's not generally practical or safe to try and replace one cell in an otherwise good pack. In any case, replacing a failed cell is unwise because other cells within the pack may already be approaching a similar condition. It is safer to discard such a battery rather than try and repair it.

Using older batteries

When using older or well used cells, it is safer to use more conservative voltage values for charging and discharging than for new cells. This will reduce the voltage range over which the pack will operate, and therefore reduce the chance of an individual cell within a pack from becoming overcharged or over discharged.

Cycle life

A good quality LiPo battery, if treated favourably might reach a useful cycle life of 200-300 cycles or more. However, cells which have been pushed very hard may only achieve a fraction of this. Cycle life will be best when the cells enjoy an easy life in terms of the conditions of both usage and storage.

When to retire batteries

For safety reasons, any LiPo battery that shows signs of trouble should be discarded, especially if it's doing a safety critical job. It should be appreciated that LiPo batteries are not as durable as other types and they will have a relatively short cycle life. The decision as to how long to keep a battery in service depends on the particular circumstances such as the amount and type of use a battery has experienced, your attitude to risk, the history of the battery and so on.

Bent, puffed or swollen cells

Batteries that have developed any kind of damage, even if only slightly so, are much more likely to give trouble than one in undamaged condition. This bent 2 cell pack suffered damage during shipping. It might be damaged internally, making it risky to put into service. No matter how disappointing, for maximum safety, damaged batteries should be discarded.

Chapter 12: Using joined LiPo packs

Joining LiPo batteries to make larger packs

Joining two or more packs to create a higher voltage or capacity battery is quite possible, provided it is done with care. However, there are a number of precautions that must be applied to do this safely. The first precaution is to ensure that the cells in the batteries concerned are extremely similar to each other.

When manufacturers build brand new multi-cell packs, they start with cells from the same manufacturing batch, thus more or less guaranteeing that the cells are virtually identical. Since they are permanently joined and share the same balancing connector, these cells will experience the same usage history and can therefore be expected to remain in a similar condition to their neighbouring cells. Therefore, if you want to use joined packs, for maximum safety it’s best to buy new packs from the same manufacturer of the capacity and voltage that you require, and to ensure that these packs share an extremely similar history for as long as you want to use them together. Take great care when connecting battery packs together ~ it is very easy to accidentally create a short circuit!

A: Joining packs in series (higher voltage, same capacity battery results)

An example of this would be when two 3S 3,700mAh LiPo packs are joined to give a 6S1P 3,700mAh battery. Another example would be when a 3S 5,000mAh pack and a 5S 5,000mAh pack are joined to give an 8S1P 5,000mAh battery. It is vital that only packs of an equal capacity are joined in series, otherwise one pack will become flat before the other, causing damage to the smaller capacity pack.

For a similar reason, it is also most important that before using series connected batteries, they are each in an equal state of charge. If packs in an unequal state of charge are joined in series, the pack with the lowest state of charge will become flat before the other. The voltage of its cells may fall below 3V each, ruining them. The safest policy is to fully charge packs before joining them in series.

Note that even if packs are of equal capacity and in an equal state of charge, the cells may in practice be of significantly different capacities (due to use, deterioration etc), and so in order to guard against damage to the weaker pack, it would be wise to apply a more conservative than normal limitation on flight time. For condition monitoring purposes it would be advisable to monitor and record the charge quantity required to restore each pack to a charged condition after each flight.

Used non-matched packs

It’s possible that you already own a pair of used but very similar packs and wish to use these in a series joined application. Depending on how similar the packs are, this is not necessarily unsafe. However there’s no guarantee that the cells in both packs will have shared the same usage history, or that they are as similar in the first place as they would be if they had come from the same manufacturing batch.

For the above reasons, joining used packs should always be considered to be an experimental process, and as such will be subject to an additional degree of uncertainty and risk. If packs are not identical, you must at least ensure that they are of the same type, manufacturer, rating, age and general condition.

Charging series-joined cells

It’s always going to be safest to charge packs individually which have been discharged while joined in series. This may not always be the most convenient solution. Cells are routinely charged together in any series wired battery, and although balancing is preferable, it is not necessarily essential on every charge.

The cells in a manufactured pack will have been matched for capacity and this safety enhancement will be missing from a series joined arrangement of packs. If you are sure that the packs are extremely similar in condition and state of charge then it is possible to consider recharging the packs in series without a balancer. If you choose to do this it is preferable to terminate charging before the cells reach a 100% full state of charge to reduce any risk of overcharging. A number of more experienced modellers do charge packs joined in this way, but the process must be considered an experimental to some extent and you should carefully assess the situation before going ahead.

Storage of series joined packs

Series joined packs may safely be stored while joined together, but as there is no advantage in doing so, it's safest to recommend that they are separated when not in use.

B: Joining packs in parallel (same voltage, higher capacity battery results)

An example of this would be where two 3S 2,500mAh LiPo packs are joined to make a 3S2P 5,000mAh battery. A suitable wiring harness would be required for this. It is vital that before connecting packs in parallel that they are in an extremely similar state of charge (within 0.03V of each other or better). If a significant voltage difference exists when they are joined a current will flow from the higher voltage pack into the other one until their voltages become identical. This current could be quite high because of the extremely low resistance in the circuit.

Charging parallel joined packs

It is possible to charge parallel joined packs while they are connected together. This would also be considered an experimental process and cannot be recommended. It is safest to charge parallel joined packs individually, joining them only when they are needed for use.

Storage of parallel-joined cells

Since cells cannot be guaranteed to behave identically, it is safest to store parallel joined packs individually, joining them only when they are needed for use.

Unequal capacities

It's not recommended to join packs of unequal capacity in parallel. In theory, it should be possible to quite safely do this. Because of the way the cells are connected, they will always remain at identical voltages, so the cells could theoretically still be expected to discharge evenly in terms of % capacity remaining.

In practice, if discharging occurs at a high rate any differences in their internal resistance may cause cells to become unequally discharged. Therefore, cells of substantially unequal capacity which are joined in parallel should only be discharged at a low current i.e. 1C or less. Practically, this means its best not to join cells of substantially different capacity if they are to be used for flight packs. If you choose to ignore this advice, at least don't come close to flattening the packs.

A reminder of the properties of joined packs:

Property	Series	Parallel
Voltage	Voltages of cells are added together	Same as for a single pack
Capacity	Same as a single pack	Capacities of packs are added together
Supplied current	Same for each pack	Shared by packs

Appendix 1: Top Tips - a summary of best practice

This section summarises some of the most important points about working with LiPo batteries. For more complete guidance, read this guide!

Standard Fire Precaution (SFP)
Recommended in all cases of short circuits, overheating, crashes, puffing/swelling etc:
1. Set the battery aside somewhere safe i.e. outside on a fireproof surface
2. Wait for at least 20-30 minutes while you keep the battery under observation.

If a fire does occur
Never breathe fumes or smoke from a LiPo battery fire.
Never use water to extinguish a fire – on a LiPo fire its like adding petrol (gasoline)

Charging
Never charge batteries above 4.2Vpc.
Maximum charge rate is 1C unless specifically permitted otherwise.
Check charger settings carefully before charging - every time.
Always remove LiPo batteries from models before charging.
Only ever use a charger specifically designed to charge LiPo cells.
Only charge in a fireproof location. (Sand lined Pyrex dish/ceramic plant pots are both good)
Monitor the charging process carefully, especially for the first few minutes.
Always verify that auto detect chargers have identified the cell count correctly.
Whenever possible, always use a balancer when charging.
Never charge a pack containing a damaged or swollen/puffed cell.
Never charge or use very cold batteries.
It's OK to charge warm batteries, but never charge hot batteries.
Check battery temperature constantly during charging. LiPo cells should not get warm.
If cells do become warm when charging, Standard Fire Precaution is recommended.
Keep your charger out of strong sunlight – LCD displays can become damaged.
Don't charge LiPo batteries inside a car - especially not while driving.
Don't block any of your charger's cooling holes e.g. by placing it on grass.
Don't top up previously charged cells.

Discharging
Never allow batteries to drop below 3.0Vpc.
Respect discharge C limits.
Provide cooling air for flight packs (not too little in summer, not too much in winter).
Always remove batteries from a model after flying.

Storage
Store cells in a fireproof location (not inside your house).
Never keep batteries in a hot car.
Ideally, store batteries between 5ºC (40ºF) and 27ºC (80ºF).

Safety
Prevent short circuits. If one occurs, Standard Fire Precaution (SFP) is recommended
If batteries become damaged, they may catch fire. SFP again recommended
Make sure cells don't become severely unbalanced.
Do ensure connectors are insulated to prevent short circuit in handling or storage
Keep all batteries out of the reach of children.
Don't carry batteries in pockets. They might short against coins or keys. Ouch!

Extending the life of cells
Use fully charged batteries soon after charging
Avoid fully discharging batteries (minimum 3.3Vpc recommended)
Stay well within rated discharge C limits
Store cells at about 3.8 - 3.9Vpc in a dry atmosphere.

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Boxed text and graph/table/drawing index

Graph, table & drawing finder

(g) = graph, (t) = table, (d) = drawing

Boxed text