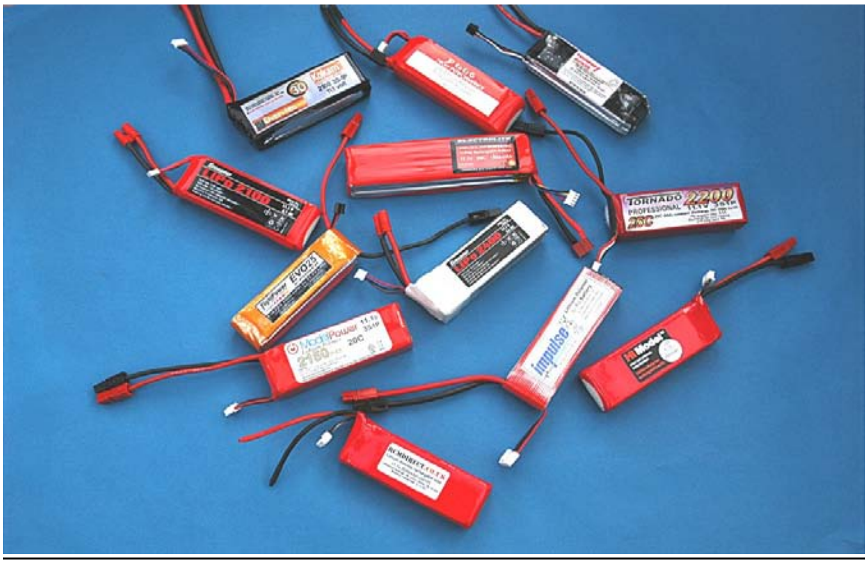
BRITISH MODEL FLYING ASSOCIATION

THE SAFE AND EFFECTIVE USE OF LITHIUM POLYMER BATTERIES IN MODEL FLYING



LITHIUM POLYMER BATTERY SAFETY BOOKLET

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BMFA Guidance Handbook

The safe and effective use of Lithium Polymer Batteries in Modelling.

General introduction.

This booklet is intended to provide a set of guide lines for modellers who wish to use Lithium Polymer (LiPo) batteries in model aircraft and associated equipment, particularly when the battery is intended to provide the primary power source for the model. It has been written mainly to emphasise the safety aspects of this area of model flying, but also contains information and guidance on best practise regarding their usage on a day to day basis.

Although lipo batteries have only recently become commercially available (compared to the earlier Nickel Cadmium/Nickel Metal Hydride types), their performance characteristics have quickly taken them to the top of the modellers wish-list. The energy density of these cells (the watt minutes/gram) is way above the other cell types we have used, and this, together with their ability to deliver high levels of power, is the reason why they are so attractive to the modeller. Their effect on electric powered model flight has been little short of amazing, and although there is little data to support the statistics, it seems likely that the proportion of powered sports flying using electric power now exceeds 50%. This rate of advance has certain disadvantages, and in this case the main one seems to be a lack of technical information relating to lipos. Whilst some technology is common to all batteries, each particular type has a different chemistry, often a different physical form, and usually quite different procedures in use. Since lipo cells and batteries are the latest to be developed, it is logical to assume that users are less familiar with them than with older types. This text will attempt to remedy that shortfall, at least to some degree.

There may be some confusion over the difference between cells and batteries, but in technical terms it is fairly simple. A cell is a single sealed unit containing an anode, a cathode, and the electrolyte. It has a voltage dependent upon the electrochemistry of the materials used, and in the case of lipo cells this is a mean voltage of 3.7V. To achieve higher voltages, single cells are assembled into series wired sets and these sets are called batteries. The number of cells in a battery is designated by a simple number and the letter S for series, so that a 2S battery or pack has 2 cells and a total mean voltage of 7.4V, a 5S battery has 5 cells and 18.5V.

Electric cells and batteries fall into two broad categories. They are either primary or secondary, dependent upon whether or not they are rechargeable. Primary cells are single use, non rechargeable units, whereas secondary cells are repeated use, re-chargeable ones. In modelling, we use both types e.g. the carbon-zinc primary cell to power a tachometer, and the nickel metal hydride secondary cell in a glow-driver. Lipo cells and batteries are therefore clearly secondary units.

Part 1 - Structure.

The main characteristics of lithium based cells are all the result of their electrochemistry and structure. The combination of lithium metal electrodes (cathode-positive and anode-negative) and separators, porous polymer plates which are saturated with a liquid electrolyte (hence the term "lithium polymer" cells), is the basic format. The first important feature of this format is that it gives a cell voltage which varies between 2.8 and 4.2V dependent upon the state of charge. When fully discharged the value can drop to 2.8V and fully charged it increases to 4.2V. These values are significantly higher than those of cells using other chemistries and although this is generally advantageous, it can give rise to difficulties when intermediate voltages are needed. The second important aspect of the lipo format is the low internal resistance which results, and this leads directly to an ability to deliver higher currents. The capacity of a cell is the third feature, and this is dependent upon the surface area of the lithium based electrodes in the cell. The greater this area, the greater the capacity of the cell and the usual geometry used to achieve increased surface area involves folding or stacking multiple layers to keep the overall dimensions of the cells and batteries as convenient as possible. Each cell is then sealed within a flexible polymer sheath to prevent loss of electrolyte, and in most batteries a number of identical cells are assembled in a series stack to provide the total voltage required (based upon multiples of the maximum 4.2 volts). In the case of a battery, the wiring normally consists of main power cables (black -ve and red +ve) which deliver the full series voltage of the pack, and an additional multiwire balancing connector (see later notes) and these are sealed into the unit during assembly.

A typical group of Lithium Polymer batteries.

Characteristics.

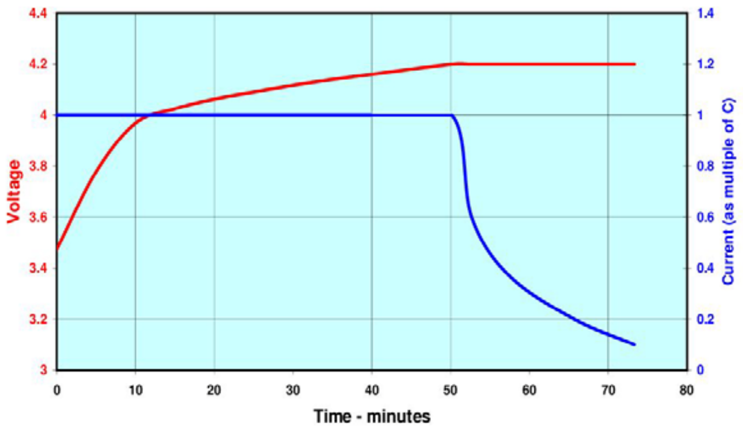
Capacity. If we consider the capacity of a lipo cell/battery then we need to adopt a slightly different system to that used with previous cell types. Whilst the capacity itself is measured in ampere hours (Ah) or milliampere hours (mAh) for smaller packs, we also link this to a C rating for the pack which is actually a measure of rate of discharge (or charge). A 1C rate is equivalent to a complete discharge in one hour so that the current drawn will be the Ah capacity numerically expressed in Amps. Multiples of C (2C, 5C, 20C etc.) would involve a current draw increased by the same multiple with the time period decreased in the same ratio. A theoretical example would be a 3500 mAh battery discharged at 2C when 7000 mA (7.0 Amps) drawn from the pack would last for 30 minutes, or the same battery re-charged at 0.5C when the charging current would be 1750 mAh (1.75 Amps) and the pack would take 2 hours to fully recharge from empty. These values are purely theoretical since they take no account of losses during the process.

One additional application of C ratings is in terms of maximum discharge rates. The maximum current which can be safely drawn from a battery is one way of measuring the quality of a pack, so identical capacity packs can be rated differently. A 2000 mAh pack rated at 20C should be limited to a maximum discharge current of "20x2 = 40 Amps", whereas a 2000 mAh pack rated at 50C can theoretically be loaded at "50x2 = 100 Amps". These C ratings are established by the manufacturers and there is some variation in the interpretation of this assessment. Modellers are therefore recommended to approach such maximum currents with caution.

Charging. The voltage range of a lipo cell is the main factor affecting the charging and discharging procedures. This range, from 2.8 to 4.2 volts, is so different to other types of cell that its use in modelling needs to be very carefully considered. The batteries must be supported by dedicated equipment (i.e. it is not possible to use equipment which was solely designed for other types of battery/cell) and this applies to all stages of their usage.

The first, and most obvious area to consider is the charging of lipos. The charging is described as a two stage constant current/constant voltage process. As described above, a cell or battery in need of re-charge will have a no-load voltage of less than 4.2 volts but more than 2.8 volts per cell, depending upon the level of discharge. Stage 1 in the charging process involves setting a suitable maximum current, and during this period the voltage of each cell gradually rises until it reaches 4.2V. In the simplest equipment the current remains constant at the pre-set value, but in more advanced chargers it may vary to protect the battery. Once the voltage of the cells reaches 4.2, Stage 2 commences and the charger holds the voltages at 4.2 but gradually reduces the current until it reaches 10% or less of the maximum value. At this point the battery/cell is considered fully charged.

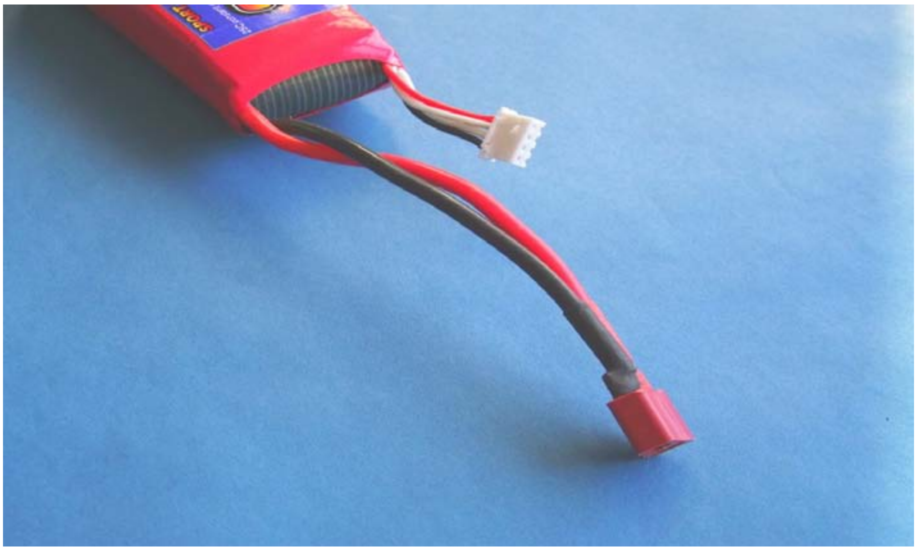
Graph 1 - Typical Charge Curve for single LiPo cell.



The most critical aspect of charging lipos is the maximum voltage. The upper limit of 4.2 volts should never be exceeded and this factor will be covered in more detail in the Safety section. Modern chargers designed specifically to deal with Lithium cells are remarkably sophisticated devices, and are programmable to allow this fairly complex charge procedure to be conducted automatically, but as we will emphasise later, it is still safest to supervise the process. When we consider the charging of batteries (i.e. 2S and above) rather than single cells, then we need to include consideration of an additional factor. The production of lipo cells is prone to introducing slight variations in the final cell units. This means that, when assembled in a series pack, this slight variation can cause the voltages, charge capacities, and other parameters to fluctuate slightly from cell to cell. If no action is taken, each charge and discharge cycle then causes these variations to grow until the overall performance of the pack begins to deteriorate, eventually leading to failure.

A range of typical chargers.

This behaviour is termed "imbalance", and the method of prevention depends upon charging the pack so that the individual cell voltages are kept as close to each other as possible. This procedure is termed "balance charging", and it is achieved by allowing the charger to read the individual cell voltages throughout the charge process. The battery has an additional set of wires connected to each of the internal cell junctions and fitted with a multi-pin connector. The number of wires in this connector is one more that the number of cells (e.g. 5 wires for a 4S pack), and the charger can then measure the voltage of each cell individually. If any imbalance is detected, the charger modifies the charge applied (increasing the charge rate for low cells and/or decreasing it for high cells), until the cell voltages are exactly balanced, particularly at the completion of the charge when all cells should be at 4.2 volts.



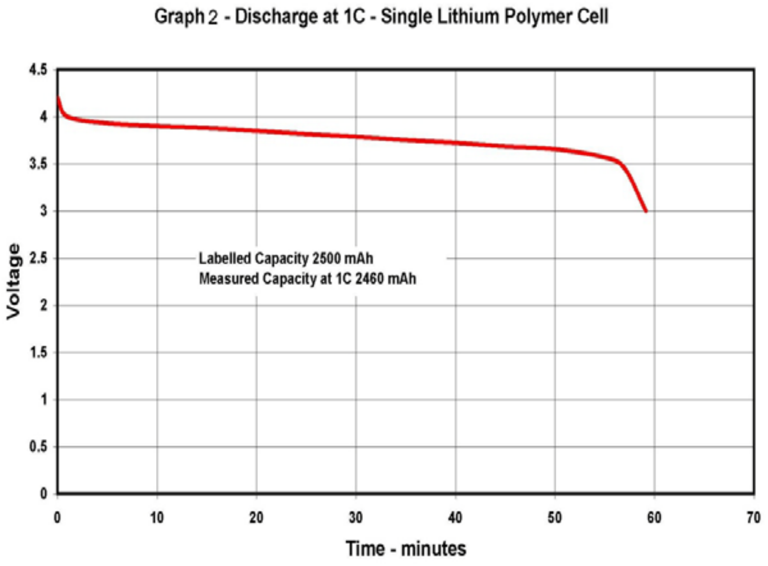
Main Power Leads and Balance Lead on LiPo Battery

Rate of Charge. The optimum rate of charge for lipos was initially 1C (i.e. 2A for a 2000 mAh pack), at which rate an empty pack would take, say, 1 hour and 15 minutes to re-charge completely (above the theoretical 1 hour because of losses in the process). Lower rates can be used, but there is little advantage in reducing the rate below 1C.When it comes to the use of higher rates (above 1C), the longer term effect on the battery has to be considered.

All lipo cells deteriorate with use. Each charge and discharge cycle gives a slight reduction in capacity of the pack. In the best of circumstances, this reduction is very small and the pack will continue to perform consistently over several hundred cycles before the gradual deterioration produces a significant loss in capacity. These ideal circumstances involve every aspect of the use of the pack. This means that the charging, discharging, storage, physical treatment, temperature fluctuations, and other minor factors can all affect the life of the pack measured in terms of its capacity. If the use of the pack involves any of these factors being outside their ideal values, the pack will deteriorate more quickly with the rate being linked to the magnitude of the parameter variation.

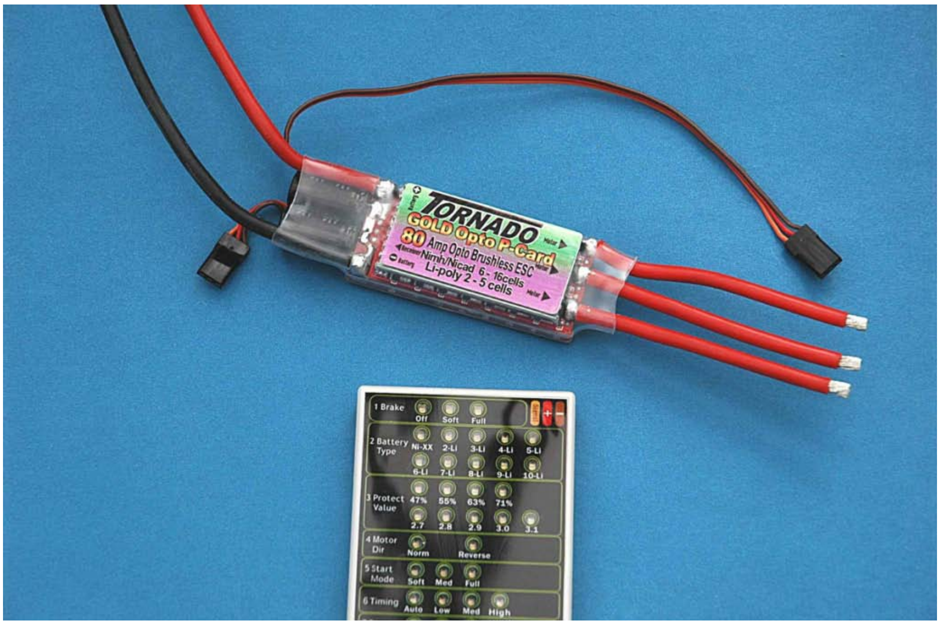
If the ideal rate of charge is 1C, then using higher values is one such example of this effect. That is not to say that higher charge rates cannot be used if the manufacturer specifies that they can. Only that this practice comes at a price involving the reduction in the working life of the pack.

Discharging. This is usually the use of the pack to provide the energy to power the model in which it is installed, and the critical factor is the maximum current draw. As the pack discharges, the internal resistance of the cells means that part of the energy is converted into heat, and the higher the current, the higher the temperature rise. When a model is set up for electric flight it is vital to know what current will be drawn at full throttle and to be certain that this value neither exceeds the pack specification (in terms of its C rating), nor leads to excessive pack temperatures during a flight. The time factor is also important since the temperature rise at constant load increases with time. The effect of any in-flight cooling must be considered, but simply testing the temperature of the pack surface at the end of a flight can be a useful guide. This should never become uncomfortable to the touch, and for minimum battery deterioration, the pack surface should be just warm at the end of the discharge.



The use of the throttle (via the ESC) is obviously important, since reduced throttle means reduced current draw, but the ESC has another even more important role to play in the maintenance of lipo packs. The ESC must be one which is designed to operate with lipo batteries and most modern units are specified for the combination of a lipo battery and a brushless motor. Care must be taken to check that the voltage range of the ESC covers the maximum, fully charged, voltage of the battery, that the maximum specified current of the ESC is above the maximum current to be drawn for the pack (ideally with a suitable safety margin), and most importantly, that the ESC has a safety cut-off voltage. We have previously referred to the minimum safe voltage of a lipo cell being 2.8V. During any discharge then, the voltage drops steadily from the start value (usually 4.2V per cell) but the discharge must be terminated before any cell drops below 2.8V.

The problem of cell variation (which is controlled by balance charging during the charging process) is also present during discharge, and there is currently no means of balancing a lipo pack during discharge. Since the ESC measures the pack voltage rather than individual cell voltages, this can lead to the over-discharge of cells. If the cut-off voltage of the ESC is set to cell count x 2.8V (e.g. 4 x 2.8 = 11.2V for a 4S pack) but cell variation leads to a range of cell voltages at the end of discharge, then we might get 4 cells with final voltages of say 2.6, 2.8, 2.85 and 2.95V. The cut-off will operate at this point for the same total of 11.2V but cell 1 has been over-discharged. Over repeated cycles this situation can only worsen, until eventually cell 1 will fail and the pack becomes useless. The prevention, or at least minimisation, of this effect is achieved by setting the cell cut-off voltage to a higher value of say 3.0 or 3.2V. This cannot prevent the irregular voltages during discharge, but it can set the cut-off to give a minimum pack voltage of 12V or above (4 x 3.0V) and thereby minimise the chance of any single cell falling below 2.8V. Most good ESCs will have such a programmable feature and it is wise to utilise it.



An ESC with programmer allowing Cut-off voltage to be programmed.

Storage. In some ways, the storage of lipos is often considered to be less important than the charging and discharging of them. You will see that, in the Safety Section of this document, this is not a wise assumption, and that each modeller should pay the same attention to this aspect as to the others. It must always be remembered that batteries store energy, and the more batteries you have in one location, the more energy is concentrated at that point. Even packs which are largely discharged can still provide enough energy to cause problems if shorts occur.

Lipo batteries have excellent charge retention. If left for a period without use there is very little self-discharge over quite long periods, especially if the storage is temperature stable (within say 10^{o} to 25^{o}C). This obviously also applies to short term storage, as perhaps might be the case where batteries are charged 1 or 2 days before the flying session. If the storage is going to be for a period of months (perhaps over winter) then the condition of the packs is best controlled by setting the voltage to an intermediate value. There may not be a strictly technical reason for this but a voltage of around 60% of the empty/full range (say between 3.6 and 3.8 volts) seems to be ideal. The comments above on charging and discharging lipos clearly indicates that the problem areas for these batteries are at the limits of the voltage range, and it would be logical to assume that storage voltages are best set at the mean value of this range. Most other features of the storage of lipo packs are linked to the safety of this aspect and are covered in more detail later in this booklet.

Secondary Factors.

There are a number of other aspects of the use of lipos by modellers which have been grouped here for convenience. Whilst these are of less importance than those previously covered, it should be understood that no factor relating to the safe and effective use of these batteries and cells should ever be ignored, and the more information and experience a modeller can gain in this area, the more he will be able to appreciate the benefits to be gained from their use.

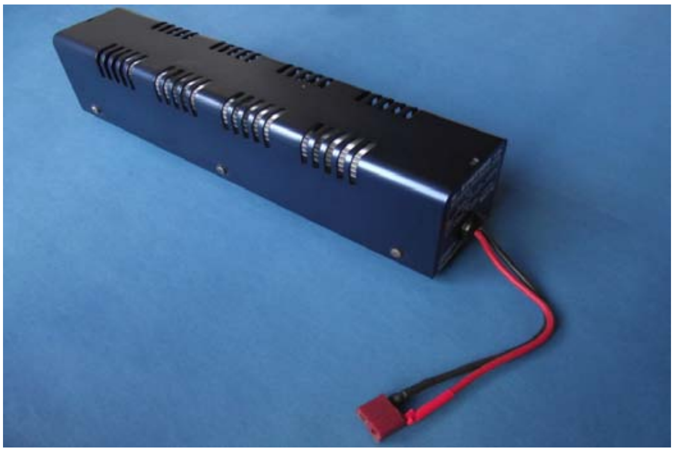
Ageing. As mentioned earlier, the cyclic use of lipos leads to a gradual loss of performance, and this means that they have a limited life, although this is measured in terms of the number of charge/discharge cycles the battery has endured, rather than a period measured in days and months. The time period since the battery was purchased is of little relevance, and the age of the pack is best measured in terms of performance i.e. the capacity, current delivery, voltage holding, and physical condition of the unit. This leads, at least with the average modeller, to a largely subjective assessment of the point where a pack reaches the end of its life as a useful source of power, though it is not unusual for a pack which no longer delivers high performance in a primary role to be downgraded for use in a less demanding secondary role.

If the end of the initial period is signalled by physical damage (perhaps resulting from a model crash) then even a secondary role may be unsafe, especially if a cell or cells show signs of swelling. If the swelling occurs as a result of other factors i.e. no crash involved, then the same principle applies. The pack should be retired and safely disposed of.

Dischargers. In general terms, the need to discharge or cycle a battery (other than to prepare a pack for long term storage) is quite rare with lipos. They have absolutely no "memory effect" and are quite happy with short term storage at any charge level. Despite this situation, many modern chargers have a discharge facility, and whilst this may not be essential, it can sometimes be useful.

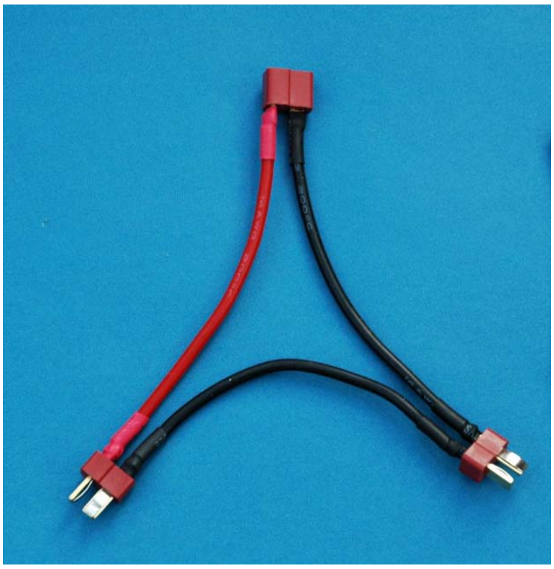
The advantages of a built -in discharger are in terms of recording data, especially if the unit has an interface which allows the data to be recorded via a computer. The use of such a unit means that the voltage of the pack can be checked at any time during discharge, and if the balance lead is used, the voltage of the individual cells can also be checked. The system also records the capacity of the pack (usually in mAh) so that a check on pack discharge from full to empty can be compared to the maker's specified value. Remember that losses occur during discharge, proportional to the current draw, so that the measured capacity will invariably be lower that the specified value. The difference between the two values is often a good indicator of the quality of the pack (smaller being better).

The other important advantage is that the use of a discharger will normally include a voltage safety cut-off, and this can be set to ensure that no cell in the pack ever approaches a minimum voltage which could damage the cell. So far as disadvantages are concerned, the main one is in terms of power limitation. Chargers have power limits, as do all electronic units. Expressed in watts, this is the maximum power output during charging and is the product of the output amps and volts. This is typically in the order of 50 to 200 watts, but even this has limitations. If a 50 watt charger was required to charge a 4S 3000 mAh pack at 3 amps it would need an output of just over 50 watts and would probably struggle to deliver this. For any larger pack it would only be able to handle a charging rate of less than 1C and the charge time would increase accordingly. In the case of the discharge function, the power limitation is much higher with ratings being as low as 2 watts so that the battery above would only discharge at 0.12 amps and could take up to 30 hours to complete the process. Some top end charger/dischargers have the facility to operate with add-on resistive loads which allow discharge currents up to 10 or even 20amps, but these are expensive units.



An Add-on Resistance (15 ohms) to allow higher discharges.

Combining Packs. Whilst batteries are available with high capacities (up to 6500 mAh) and high voltage (up to 6S) these units are expensive and modellers can achieve a similar performance by combining smaller packs. This combination can take the form of a series or a parallel assembly. An example of a series combination would be a pair of identical 3S 3000 mAh packs combined to act as a single 6S pack (and hence provide a maximum voltage of 25.2 V) but with the same 3000 mAh capacity of a single pack. For a parallel combination the capacity would double to 6000 mAh but the maximum voltage would remain at 12.6 V. This combination involves a suitable wiring harness in which the two (or occasionally more) batteries are linked by their main output leads. This harness is designed and manufactured specifically to achieve this end.



A wiring harness to combine two packs in series.

It is also possible to combine the balance leads so that the two packs can be charged as a single unit, but this arrangement is more difficult with a risk of shorting. The safest procedure is to treat the two batteries as individual units at all times other than flying the model so that the combination is removed from the model at the completion of a flight, the packs separated from the harness, and recharged as individual units. This is particularly important with parallel combinations where cell imbalance can easily be exacerbated.

Ambient Temperatures. As with almost all battery types, there is always a proportion of the energy flow through a battery which is used to overcome the internal resistance of the cells. This lost energy is usually converted to heat (though this is complicated by the endothermic or exothermic nature of the chemical reactions involved in the electrolysis) and it is possible for the pack to heat up during both charge and discharge. These losses increase with higher currents so the pack can overheat at high discharge rates. If the temperature rise is moderate, it can be an advantage as the internal resistance of the cells decreases at higher temperatures which allows higher voltage levels and also reduces the heat developed. The worst scenario would involve the effect on the pack during high ambient temperatures. If the pack were to be left in model exposed to a hot summer sun, then the pack might already be above 30^{o}C at the start of a flight, and the increase in temperature during the flight could quite possibly damage the cells.

The reverse scenario of flying the model when ambient temperatures are particularly low is more complex. Here the problem is not only the increase in the internal resistance at lower temperatures (the reverse of the effect at higher temperatures) but there are also changes to the electrochemistry at lower temperatures which makes the cells more liable to damage. Current draws which are no problem at 20^{o}C, become damaging at 5^{o}C. This may be a short term problem, since the pack does warm up as the flight proceeds, but the damage is accumulative and non-recoverable. In the case of charging (particularly field charging), attempting to charge a pack when its body temperature is below 5^{o}C is particularly damaging and should be avoided. It need not, however, curtail a winter flying session, as use of a designed pack warmer, or even a simple hand warmer, can keep your battery in good condition for flight and recharge.

Use of lipo batteries for Txs and Rxs. Our RC equipment was traditionally designed to operate off 4.8V for the Rx and 9.6V for the Tx. You will note that these values do not match a multiple of 3.7V (the mean lipo cell voltage) and this can give rise to some problems. Manufacturers are now starting to redesign the circuitry on their RC units to include the suitability of lipo packs, but in the case of units designed for NiCd or NiMH cells using a multiple of 1.2V, conversion of the units to accept lipo packs is much more problematic. For receivers, the simplest solution is to use an addition transformer between the battery and the receiver/servos. These units are called UBECs and take the voltage of the battery and convert it into the 4.8V required. Of course the importance here is to be certain that the specification of the UBEC matches the needs of the flight system in the same way as the electronic speed control must.

If you wish to convert an existing Tx to lipo batteries, the recommended procedure is to start by contacting the manufacturer/importer of the equipment to see if this is an allowable procedure. If you are not given clearance to make this change but you still go ahead then you will run the risk of damaging your Tx and, in addition, any warranty you have will be invalid, you may not be able to have the equipment serviced and the CE mark on the transmitter will also be invalid. The legal responsibility that you then take on yourself is considerable and must not be underrated.

Part 2 - Safety.

This is, then, the crux of the matter. Lipos are a tremendous advance for modellers and can help our flying and general modelling enormously. But, and it is a large but, you and others cannot enjoy modelling IF IT IS NOT SAFE. Of course, like any situation involving risk, use of the correct procedures in a careful attentive manner, can reduce these risks to an acceptable level. In the case of lipo batteries the main risk involves the possibility of a battery fire, and the causes of such fires need to be understood before they can be avoided.

The causes of ignition. Any lipo cell in any battery has the potential to ignite. The cell contains some metallic lithium which is inflammable, and lithium cobalt oxide, which, under certain conditions, can release gaseous oxygen. If there is a source of ignition available, a cell fire can occur. The source of ignition is usually a temperature increase in the cell, but the problem here is that one result of the changes which release oxygen is a further increase in temperature until thermal runaway occurs, and once that point is reached, ignition and a cell fire cannot be avoided. The fire is self-sustaining since it is independent of atmospheric oxygen. It is probably more correct to call it a chemical flare, since it is extremely fierce, pressurised, releases toxic chemicals, and burns at a much higher temperature than a normal flame. Once ignition has occurred, the fire cannot be extinguished, fire extinguishers are of little use, water will only exacerbate the situation, and the only way to minimise the effects of the combustion is to contain it, preferably within fire-proof container.

A Typical safety sack

There are some useful accessories available through the trade and an example is the fireproof envelopes which many suppliers sell. These can be used in any circumstances where there might be a question about the stability of a lipo. Containing the doubtful battery (perhaps one from a model crash or one that indicates swollen cells) in such a sack will not prevent possible ignition, but it will contain the fire and will certainly reduce its effect on the surroundings.

It is important to realise that the factors leading to ignition are not inevitable, and actually need never occur. Every lipo fire is the result of misuse of the battery (but not every misuse leads to a fire). By misuse we mean placing the pack in any situation which is outside of the specified/recommended conditions. It may be an accidental error on the part of the user (we are assuming that it is never deliberate), it is almost certainly an avoidable error, but it is most probably an error resulting from lack of understanding, lack of attention, or lack of care. We all make mistakes, but few of them can have the possible consequences of a lipo fire. The ignition is seldom instantaneous, and there is a clue to the onset since the release of oxygen causes the polymer envelope of the cell to inflate or "puff up".

Possible Ignition Scenarios. The first, and probably most common cause of ignition, is over-charging. This is in terms of voltage (and not current where rates above 1C are sometimes specified) such that the cell voltage is never normally taken above 4.2V. If the voltage of a cell is allowed to creep above 4.2V the process of releasing oxygen can begin at values as low as 4.25V. This also causes the cell to heat further and progress towards the critical runaway point. The damaged state of such a cell then means that discharge and re-charge (i.e. normal use) exacerbates the problem, the cell begins to swell, and the risk of ignition is getting progressively larger. It is for this reason that any pack showing swelling of one or more cells should be disposed of. It is also the reason why the following restrictions should be observed.

1) Always arrange a model so that the flight battery can be easily removed, and always remove the battery to re-charge it.

2) Never leave a battery unobserved during re-charge. Always stay in or around the charging location so that you can periodically check for any signs of battery or charger distress.

3) For series packs (2S and above) always balance charge to prevent individual cells being overcharged.

4) Use an effective and reliable charger with occasional checks on output levels and balancing effectiveness.

5) Periodically check the temperature of a pack on charge and stop the process if it becomes hotter than expected.

6) Never charge a pack which is already hot, either from a previous flight, or from its recent position (e.g. behind a car windscreen in sunny weather). Allow it to cool to ambient temperature first.

7) Always double (or even triple) check that the charger is set to the correct voltage i.e. that the cell count of the pack matches the charger voltage limit.

The second cause of ignition can be over-discharging. Although the reactions are different to the previous case, the end result can be the same. If power is taken from the pack until the voltage of one or more cells is reduced below 2.8V copper filaments can be deposited between the anode and cathode. Although extremely fine, these can act like internal shorts, particularly during a following re-charge. Again, this process is accumulative, and leads to excessive heating during charge/discharge, which in turn leads to the release of oxygen and the same end result. In a normal model, the control of the voltage cut-off is via the ESC. As mentioned earlier, this has limitations, but setting the value higher that the theoretical minimum of 2.8V, at 3.0 or even up to 3.3V, does provide a safety margin. It is also a good thing to periodically check the reliability and accuracy of this cut-off, but this may not be easy to test.

Over-discharging can also take the form of too rapid a discharge i.e. too high a discharge current. This is a simple case of overheating resulting from high current flow through the internal resistance of the cell. The link between current, voltage and resistance is simple Ohms Law, but internal resistance is more complex than a simple resistive load and this does complicate the calculations. In general terms, better quality packs have lower internal resistance and are therefore able to handle higher currents without exceeding maximum heat levels. Remember also that the internal temperature rise of the pack depends on the total energy converted to heat over the period of the current flow so that short bursts of high current are less damaging than continuous high current. The effects are accumulative of course, and in the end deterioration and the production of oxygen will commence.

A full external short would give rise to a very high current (as well as a very large spark) and this can be thought of as an extreme form of this case. Such an event might be the result of a model crash, or may be an inadvertent error by the user such as a reversed power connection in a non-polarised set up. The level of deterioration in a cell subjected to an open short can be very high with immediate and very obvious problems, but they can also be more subtle. If the energy release takes the cell internal temperature to a level where the oxygen release is initiated, there may be little obvious evidence of the damage and it may be an appreciable time before the cell goes critical (possibly during the following flight).

A deliberate LiPo fire using a safety sack to contain the flames.

The model crash scenario can also lead to somewhat less dramatic, but equally destructive and longer term problems. The structure of lipo batteries is not one that creates a rigid form (compared, say, to the cylindrical metal cased cells of nickel metal hydride packs). The outer sleeve of metallised mylar and the inner polymer sleeves of the cells offer very limited resistance to distortion and puncture. A pack which has been involved with a model crash should be very carefully examined, even if it appears undamaged. The possibility of unseen internal damage is always there, and even small leaks can lead to problems. Any aspect of damage may trigger the chain of events which creates ignition, sometimes quickly, and sometimes more delayed, and the only totally safe solution is to dispose of the pack. Even less dramatic situations can lead to problems. The process of simply handling the packs, fitting into and out of models, moving around on the workbench, and transporting from place to place, (not to mention dropping on the floor) can cause nicks and dints which certainly accumulate over time. Whilst these will probably not lead to ignition on their own, and it is not recommended that packs should be disposed of simply because they are scruffy, it is certainly a good reason to keep a closer eye on them than you otherwise might, and any sign of swelling should be treated very cautiously.

Another important factor in the safe use of lipos is their storage. This was initially referred to in the first part of this document but now needs to be considered in more detail from a safety point of view. The storage of lipo batteries should be an organised procedure. There may be some concern over assembling your batteries into one location, as this may seem to be concentrating inflammable units such that any problem will quickly involve all of the packs. Providing that the storage is secure, flame-proof, and rigid, any problem which occurs should be contained, and this is better than the alternative. It also follows that the storage container should be located, if possible, away from situations where the combustion might spread to the surroundings. Homes and other buildings should never be risked, vehicles should not be used except for transport, and the storage unit should be located well clear of any combustible materials. This may be very difficult to achieve, but modellers are resourceful individuals and are encouraged here to do their best to create a safe storage location. One further difficulty is the need to keep the stored batteries at a stable temperature as mentioned earlier, and it is true that this requirement may be difficult to combine with those above.

The ideal container is a metal box or trunk. These are certainly rigid and fire-proof, but they are also waterproof and usually lockable for security. Many modellers use ex-army ammunition boxes, which are ideal and reasonably priced. Although the box should be waterproof, they should not be airproof, as, in the worst case, the combustion gases need to escape from the container. If you feel the edge seal on the lid is too good then remove a short length of the sealant, and if that is not possible, drill one small (say 2 mm) hole in the side of the box to relieve any build-up of pressure. The other aspect of a metal container to be considered is the avoidance of short circuits. Every battery placed in the box should be checked to ensure that there is no possibility of accidental contact between any of the exposed connectors or leads and the metallic case they are to be placed in. If possible, it is best to keep all batteries separated by fitting a honeycomb of internal dividers (plus sides and base) of non-conducting, non-flammable material to the box. Plasterboard is a good choice for this.

The remains of a burnt-out LiPo still in a safety sack.

All of the above scenarios have a common theme. The spontaneous ignition of a lipo battery has to be preceded by a higher than usual internal temperature in one or more cells. The origins of this higher temperature can be complex or simple, internal or external, chemical or electrical or physical, but clearly, no lipo battery bursts into flames for no reason. It may not always be obvious why a lipo battery has ignited, but there is still a reason, and in the vast majority of cases, this is linked to the treatment history of the pack during the period prior to the occurrence. The other aspect of these scenarios is that problems can occur as a result of a combination of circumstances. A pack may be in a model that crashes and is later subject to a degree of over-charging. Neither of these two factors may individually be sufficient to initiate ignition, but the combined effect may be critical. It is always wise to remember the accumulative nature of the changes induced in a pack by each of the situations covered in this section.

As a safety guide, this document has been written to cover the area in a fair amount of detail, particularly with regard to battery fires since this is the most obvious and high risk aspect of their use in modelling. It is hoped, however, that readers are aware that the incidence of such fires in the UK modelling world is remarkably low. The vast majority of modellers who use the batteries, do so in a safe and responsible manner and we are sure that they will continue to do so.

Other dangers. There are other aspects of the use of lipos which may pose danger. We have already referred to the danger of shorts between the leads/connectors of a pack, but there have been instances of an individual inadvertently causing such a short by means of an identity bracelet, a metal watch strap, a set of keys, or other metallic objects. The contact at the point where the short occurs often causes an instantaneous weld, and this means that there can be a very high current flow through this accidental circuit for several seconds rather than for a fraction of a second. If this happens, the components of the circuit can heat up rapidly to a very high temperature giving rise to severe burns if in contact with the individual's skin.

This possibility again raises the need for the modeller to pay particular attention to the leads and connectors of lipos. There is a range of connectors which are suitable for use in this situation, some of which are polarised and have at least one half of the connector where the terminals are prevented from accidental shorts by the physical design. Ideally, both parts of the connector should have the contacts shrouded, but if this is not possible, then temporary protection can be provided so that the contacts are exposed only when the pack is being connected or disconnected, and are, at all other times, protected from accidental contacts. Leads should be regularly checked for insulation damage, and soldered joints for any sign of loosening.

Personal safety. There may be situations where a lipo fire may occur without the risk of damage to person or property. A model crash on the far side of the model flying field, where the model bursts into flames some 30 seconds later before any modeller reaches the location, might be one such. In this case, the advice to all modellers is to stay well clear of the location until the lipo fire has burnt itself out (which is usually fairly quickly). Even the use of a fire extinguisher should only be instigated later to prevent the spread of fire through the surroundings and to douse any remaining flames in the model structure. Removal of the wreckage should involve gloves as there may be toxic materials on the remains, and anyone in the area should avoid breathing any of the smoke or vapours from the combustion. If the circumstances are such that an individual receives skin burns from a lipo fire, there is apparently some danger that the application of water to the area of the burn (which is common practice) may exacerbate the absorption of toxins, and the water should be replaced by oil (cooking oil might be suitable in an emergency).

Prevention/Precaution. You must be proactive about safety. Complacency is a real problem since it leads to lack of care/attention, and any modeller can fall into this trap. Always remember what is at stake and act accordingly. In this document we have sought to offer the modeller the means of at least minimising the risks involved with the use of lipo batteries in modelling. Modellers accept that the pursuit of their hobby can involve risks ranging from modelling knife cuts to over-sensitivity to cyano-acrylates, but the majority of such incidents are short term and relatively inexpensive. The risks to the person and to property of a lipo fire are much more significant, and the precautions one should take to prevent such occurrences should be as thorough and consistently followed as is possible. Remember the BMFA motto - SAFETY IS NO ACCIDENT.

Disposal of used lipo batteries. When a lipo reaches the end of its useful life it should be disposed of in a responsible manner. The unfortunate aspect of this is that the definition of ideal disposal is very unclear. One thing that must be stated is that the widespread suggestion that disposal should be preceded by degradation in a bucket of salt water is not now recommended. This process adds Lithium salts to the water, and the disposal of this through our normal drainage systems is likely to affect the work of our Water Authorities, who use Lithium as a trace element when locating leaks. At the time of writing, the best available disposal procedure is via the local authority Environment and Waste department, but not through the weekly collection. Most authorities have a web-site where you can find the location and other details of their waste re-cycling collection system and this usually includes a collection point for spent batteries.

The lipos you wish to dispose of should firstly be discharged to a minimum voltage. In this case you can afford to drain them as near to zero volts as possible. Do this in a controlled manner using a suitable resistance matched to the battery so that neither the battery nor the resistance overheat. DO NOT attempt to discharge the battery by shorting the leads for reasons previously covered. Once the discharge is complete, the batteries should be placed in a stout cardboard box or similar, bound with tape, labelled with "SPENT LITHIUM BATTERIES FOR RECYCLING" and transported to the local authority Household Waste Recycling Facility where there will almost certainly be a location specifically for such items. There is also the National "Battery Back" Scheme under which battery retailers are obliged to accept returned spent batteries from their customers, and model shops are included in the scheme. If you wish to take advantage of this arrangement it would seem sensible to confirm that your local shop takes part in the scheme. The procedure is clearly less convenient if your batteries have been purchased by mail order.

Other sources of guidance. All manufacturers and distributors of Lithium Polymer batteries include a Safety Leaflet with any lipo they sell. These vary somewhat, depending on the source, but they normally contain good advice regarding the utilisation of their product. It is well worthwhile reading these carefully and keeping at least one example for regular re-reading. It is tempting to think that accidents don't happen to you because of your knowledge and experience, but always remember that it is your actions which will determine if you will have a problem with lipos, and any reminder of best practice can help to protect you from the possibility.

There is also some guidance in the current BMFA Handbook but this may change in the future. If you want a more detailed reference to lipo batteries we can recommend "The Gibbs Guide to Lithium Polymer Batteries". This is available from Andrew Gibbs Website at www.gibbsguides.com