ebikers, so I decided to put together an article to cover the basics.

Cells in Parallel, the P-Count

[In this article, I will use a small rectangle-shaped pack as an example, which is the easiest style to understand when learning these principles. Once you have a firm grasp of this, you can easily scale your pack up to different shapes and sizes]

If you take several cells and connect their same-type electrodes in **parallel**, they all will **act as though they are one large cell**. Also, when you first connect them to each other, they MUST be at the same level of charge [The positive electrode is the Cathode, and the negative electrode is the Anode. In the pics below, the positive is a red plus sign, the negative is a black dash].

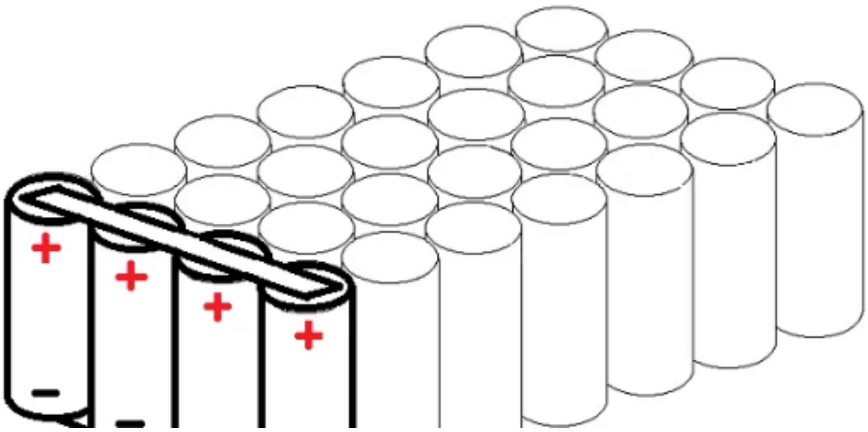
By that I mean…if you connect a fully charged cell “in parallel” to a cell that is low, the high cell will try to charge up the low cell in just a

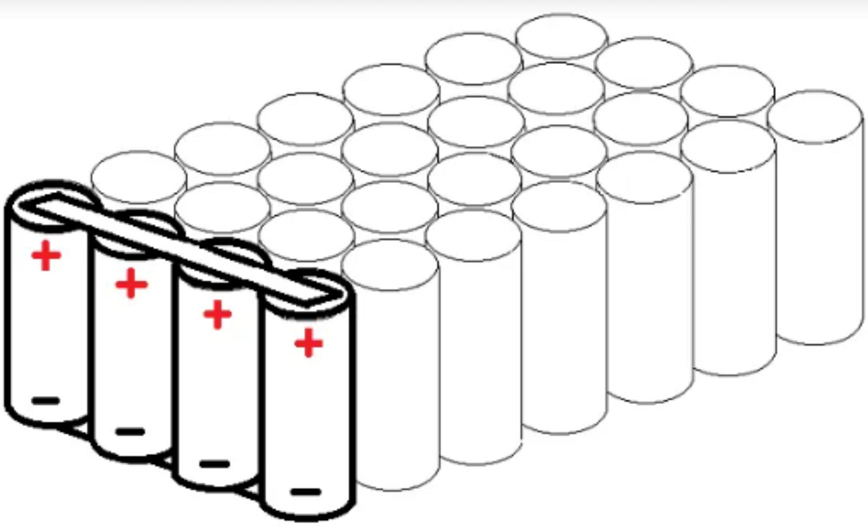
the negative electrode is the Anode. In the pics below, the positive is a red plus sign, the

negative is a black dash].

By that I mean…if you connect a fully charged cell “in parallel” to a cell that is low, the high cell will try to charge up the low cell in just a
few seconds, since there is no built-in resistance between them across the connecting bus to slow things down. A rapid equalization will absolutely cause both of them to get VERY hot. Permanent damage is the least that will happen, and most likely one of them (or both) will go up in flames. However, if there is only a tenth of a volt in difference between them, that would not be a

problem (for instance, from 4.1V to 4.2V would be OK, they would both equalize at 4.15V).





Four cells in parallel in a 7S/4P pack (28 cells). There is a full-length electrically-connecting metal strip (bus) on the top and the bottom of these four cells. The four cells in parallel can be configured in any shape, but having them in a straight line is the easiest introduction to understanding it.

The P-count determines the **capacity** of the pack in Amp-hours (Ah), and it also determines the amount of **current** the pack will be able to produce, measured in amps. For this example, we will use my favorite ebike cell, the Samsung 30Q. It is factory-rated as having 3000-mAh (milli-Amp-hours), which is

determines the amount of **current** the pack will be able to produce, measured in amps. For this example, we will use my favorite ebike cell, the Samsung 30Q. It is factory-rated as having 3000-mAh (milli-Amp-hours), which is
the same as 3-Amp-hours (3-Ah). If you have

four in Parallel, the finished pack can be rated as 12-Ah's worth of range (4P X 3-Ah = 12-Ah).

Now we come to the amount of power that the pack can safely put out. The 30Q is a hot-rod cell (along with the HG2 and the 25R), and it is factory rated at 15-Amps continuous. However, almost all cell models get hot if you actually run them continuously at their listed rating. I recommend that nobody should ever let their pack get hotter than 140F (60C) under any conditions. Doing that will lead to a very short pack life.

Fortunately, ebikes usually only draw their peak amps for a few seconds while accelerating. Once you reach a cruise phase, the continuous amps that the controller and motor will draw is MUCH lower when you are

Fortunately, ebikes usually only draw their

peak amps for a few seconds while accelerating. Once you reach a cruise phase, the continuous amps that the controller and motor will draw is MUCH lower when you are simply maintaining your speed. If we use the 15A figure as our designed max amps, the pack will just get a little warm, and that means it will last a very long time. **Four 30Q cells in parallel that are rated for 15A means we can depend on getting 60A** from this pack without damage (4P X 15A = 60A).

Cells in Series, the S-count

When you connect cells together in **series**, it doesn't change the amps or the capacity, it only raises the **voltage** of the pack. Hooking them up in series means that you connect the positive end of one cell (or P-group) to the negative end of the other.

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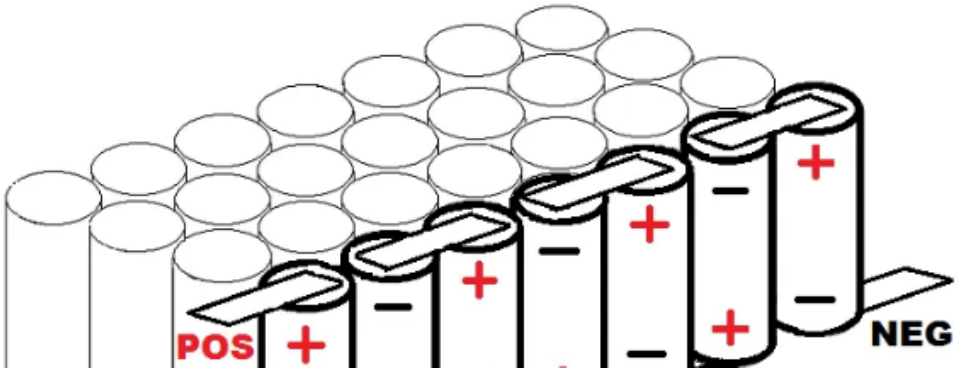
For the cylindrical 18650-format cells that are the most popular (18mm in diameter, 65mm long), they use the lithium-NCA or lithium-NCM chemistry (the cathode uses Nickel-Cobalt-Aluminum…or…Nickel-Cobalt-Manganese). Those chemistries have a nominal (average) voltage of 3.7V…and in order to get the longest possible life from the pack, use 3.3V per series-cell as the Low-Voltage-Cutoff (LVC), and 4.1V as the fully-charged target.



pack, use 3.3V per series cell as the Low Voltage-Cutoff (LVC), and 4.1V as the fully-charged target.

Seven cells in series in a 7S/4P pack, which is a nominal 24V. This is 28.7V when fully charged to 4.1V per cell.

charged to 4.1V per cell

The common max charge is 4.2V per cell, but when cells rest (for any length of time) at that high of a voltage, it will significantly degrade their life. Charge the pack to 4.1V *times* the series number.

The BMS, how to connect it?

The BMS is the Battery Management System. It performs several functions. The two fat wires (red and black) from the charger will

The BMS, how to connect it?

The BMS is the Battery Management System. It performs several functions. The two fat wires (red and black) from the charger will "bulk charge" the pack until it gets very close to being full, and then the charger will switch over to using a very low charge rate as it gets closer to being full. A 3A or 5A (continuous) charge rate is very common for the bulk charge.

This charging profile is called CC/CV, for Constant Current / Constant Voltage. It's a simple and inexpensive way to accomplish a subtle goal.

We all want an affordable battery pack, so… we buy mass-produced cells. This means that there will always be very minor differences in the internal resistances of each cell. To use the example of our theoretical 7S/4P pack above…each 4P cell-group is "seen" by the charger and controller as one large cell. The parallel connecting metal strip ensures that they all constantly equalize to each other, so

the internal resistances of each cell. To use the example of our theoretical 7S/4P pack above…each 4P cell-group is "seen" by the charger and controller as one large cell. The

parallel connecting metal strip ensures that they all constantly equalize to each other, so we must discuss them as if they were in fact, one large cell.

There are seven of these “in series” to get 24V. Now, we then set our dumb bulk DC power-supply as a charger to 3A (with NO BMS), and we use (7S X 4.1V =) 28.7V as our fully-charged goal. It works like a dream. However, only five of the P-Groups are actually at 4.1V. One P-group is at 3.9V due to high internal resistance, and another P-Group is at 4.3V due to low internal resistance. Since our dumb charger only reads the 28.7V of the assembled pack when it shuts off, it has no idea of the trouble that is brewing…

High-resistance cells run hotter than an “average-resistance” cell, but for this discussion, let’s just assume that it never gets “too hot” to cause trouble (over 140F / 60C).

High-resistance cells run hotter than an "average-resistance" cell, but for this discussion, let's just assume that it never gets "too hot" to cause trouble (over 140F / 60C). Also...cells located at the heart of a pack run hotter than cells at the edge, since the edge-located cells shed "some" heat to the outside shell of the pack.

That leaves the low-resistance cell to consider. It will dump amps faster than the other cells (when accelerating), and it will also gulp the charge faster, too. It will actually run cooler than the other "average resistance" cells, but...a bulk charger will overcharge it. If letting a pack sit overnight at 4.2V per cell will cut its life in half (compared to 4.1V per cell), then...what will letting one cell sit overnight at 4.3V do? It will lose capacity rapidly.

And that means that, the one bad cell will cause the entire P-group to experience voltage-sag near the end of a ride, and then… that one low P-group will cause the entire pack to experience voltage-sag. And this means that…for a split second on

pack to experience voltage-sag. And this means that…for a split second on
acceleration, the LVC will “think” that the entire pack is too low, and it will cut off ALL power in order to “save” the pack (one of its most important jobs).

The pack will still “work”, but…your accelerating days are over. You may have planned on buying a new pack in three years (or more), but because of one “slightly” bad cell, the entire pack is now useless to you after only a few months. This is why the bulk-charge phase (CC/Constant Current) only takes the pack to about 4.0V per cell. For the rest of the topping-charge, the Constant Voltage / CV phase is accomplished at low amps, with some sensitive electronics thrown in...

A BMS harness. The 14 wires identify this as being made for a 13S pack, which is 48V. Notice that one wire is black (or at the very least, a different color from the rest). Some BMS harnesses have a different color for each P-group, but…this will actually work fine, if you follow the common pattern.

There is one crazy "voodoo electronics" feature of a BMS. The quantity of small balancing wires is going to be…the "series number plus one". So, our theoretical 7S pack will use eight balancing wires. This just sounds nuts. Everyone who starts learning about batteries KNOWS that there are two poles (to each cell, or P-group). The red positive, and the black negative. You would think that to

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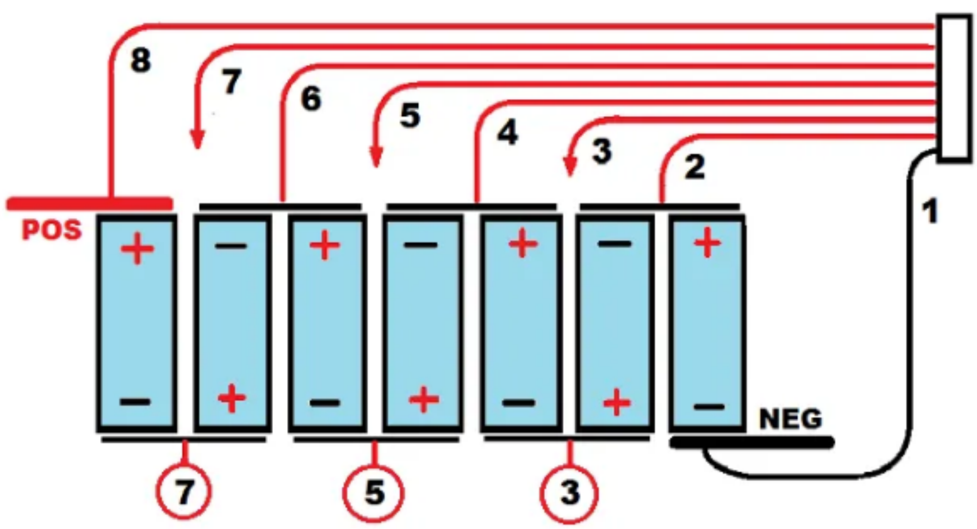
balance the charge at low amps during the

final CV phase of the charge…you would need 14 wires instead of eight, when making minor adjustments to the seven P-groups (remember, each entire P-group will act like one large cell).



A basic BMS wiring scheme for a 7S pack. Once you understand the pattern, you can expand this to any size of pack.

Look carefully at the pic above. The white plug connects the dumb harness to the smart BMS.

A basic BMS wiring scheme for a 7S pack. Once you understand the pattern, you can expand this to any size of pack.

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Look carefully at the pic above. The white plug connects the dumb harness to the smart BMS. You can see that for the BMS to access the positive and negative ends of the first cell (and the connected first P-group), it uses the number-1 and number-2 wire. However, when moving on the the second cell?…the BMS uses the #2 and #3 wires. The number two wire is sometimes used as the **positive** to the number-1 cell, and sometimes used as the **negative** to the number-2 cell (and “so on” down the line, until you reach all of the P-groups in the series string).

This eliminates 45% of the possible BMS harness wires, but..it also makes the proper connection locations confusing for new builders. Even if you are still a little confused, just follow the BMS instructions carefully.

Side note: If your battery pack dies suddenly for no obvious reason, it is usually from some

component in the BMS failing, leading to a

Side note: If your battery pack dies suddenly for no obvious reason, it is usually from some component in the BMS failing, leading to a complete drain of the pack down to zero-volts, or…a gross overcharge above 4.2V. This is why they are sometimes called a *Battery-Murder-Suspect.*

Other chemistry options?

The common **NCA/NCM** chemistries provide the best balance between capacity in a small package, and a useful amount of amps. However, there are other chemistries that might be an option for certain applications. The NCA/NCM "nominal" voltage is widely regarded as being **3.7V** per cell, and…**for the max possible life**, I'd use **3.3V** per cell as the

LVC and **4.1V** as the full charge.

LiFePO4 / LFP is commonly called "Iron Phosphate", and it has a nominal voltage of **3.2V** per cell. That means that it takes **16** LiFePO4 cells to make a **48V** pack, and

LiFePO4 / LFP is commonly called "Iron Phosphate", and it has a nominal voltage of **3.2V** per cell. That means that it takes **16** LiFePO4 cells to make a **48V** pack, and NCA/NCM only require **13** cells for 48V. However, LiFePO4 is considered the most fire-safe (sometimes found as a starter battery on small aircraft), and they also typically last about twice as long as the common NCA/NCM 18650-cell packs.

A 4S pack of LFP is the most common replacement for a 12V Lead-Acid battery pack (4P X 3.2V = 12.8V nominal).

That being said, NCA/NCM in the 18650

That being said, NCA/NCM in the 18650-format cells have a much better selection of choices, and provide high power and long range in a small package that is affordable, due to mass-production. LFP can be found in flat pouch cells, 26650's (26mm X 65mm), and large cylindrical 38120 cells (huge! 38mm X 120mm, from Headway, see below). I have actually found LiFePO4 in the 18650-format, but…the capacity was VERY low.

due to mass-production. LFP can be found in flat pouch cells, 26650's (26mm X 65mm), and large cylindrical 38120 cells (huge! 38mm X 120mm, from Headway, see below). I have actually found LiFePO4 in the 18650-format, but…the capacity was VERY low.

Headway LFP cells have threaded ends which make assembly into a pack very easy. However, the smallest one is roughly the size of two disposable D-cells.

One more obscure chemistry is Lithium-Titanate-Oxide (**LTO**). It has an even lower nominal voltage of **2.4V** per cell. It may **last ten times longer** than NCA/NCM, and it also works well in very cold weather (along with providing high current). However, I have only

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providing high current). However, I have only found them in flat pouch cells, and they are hard to find, expensive, and have few size options.

The NCA/NCM chemistries can also be found in the slightly larger cylindrical 21700-format cells. These were developed by Panasonic in partnership with Tesla electric automobiles. However, they are currently expensive, and the majority of the factory production is going into the Tesla Model-3, and also the powerwalls (a home power back-up system).

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powerwalls (a home power back-up system).

Here are four flat LFP pouch cells in series (4S). While 18650-format cells have a steel cylinder around them to provide compression and physical protection, pouch cells will need to have those added when building a pack. (notice the BMS harness has four black wires and one red). 3.2V X 4S = 12.8V nominal, for replacing a 12V lead-acid battery.

There ARE options, but…after any depth of research, almost every ebiker comes back to the 18650-format cells in the NCA or NCM chemistries.

Honeycombs are Sweet

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In the pack example above (7S / 4P), the cells are aligned in straight rows and columns, which I might refer to as “rank and file” (like soldiers marching). However, the next most popular arrangement is to nest the cells of one row into the valleys of the next, in what many have come to refer to as… a honeycomb layout. I like it, but there are benefits and drawbacks to every option.

Here are plastic end caps that help space the cells in a honeycomb arrangement.

Using a honeycomb layout is mathematically the most compact way to arrange cells. That

Using a honeycomb layout is mathematically the most compact way to arrange cells. That
being said, the common rank-and-file arrangement leaves “just enough” space between four adjacent cells to allow a thin bolt to pass through from one side plate to the other (as seen below), and a honeycomb does not.

The plastic end-cap cell holders are an important safety feature for a DIY pack. The common square layout usually positions the cells so that they are almost touching each other. That means there will be almost no aircirculation, and that leads to the cells in the center of the pack to gradually run warmer by the end of a ride.

If you have a large enough pack, and the cells can provide lots of current, then...a low-current ride will not even get them warm. At the other end of the scale, a small pack of low-current cells that are being hammered on a ride will definitely get hot. The hottest spot will always be the positive cathode tips on the cells in the center of the pack.

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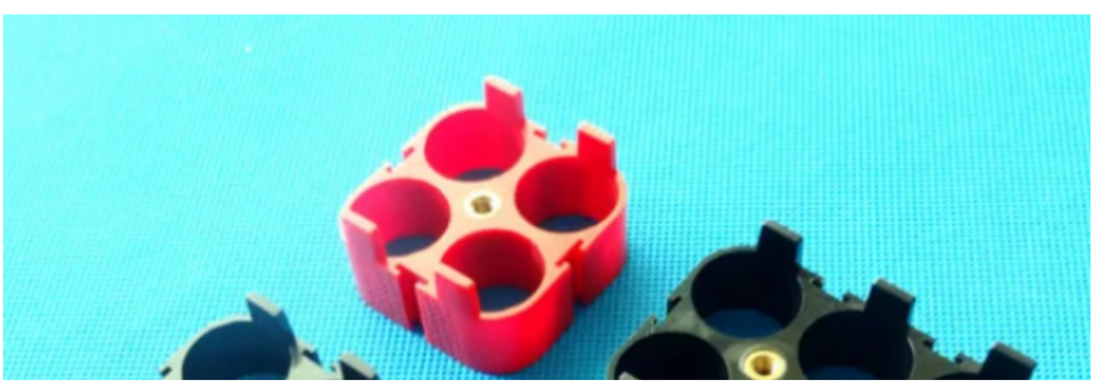
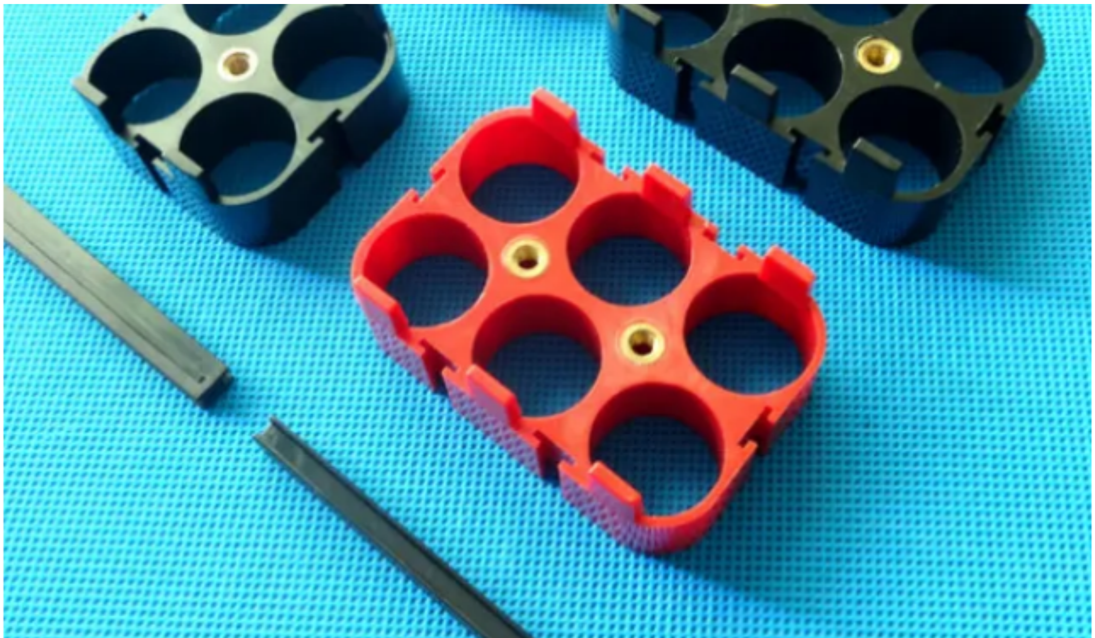




Plastic 18650 assembly caps from Ann Power. The threaded brass inserts are open all the way through. Bolts to hold both ends together can be ordered in plastic, if the common steel bolt material is a concern.

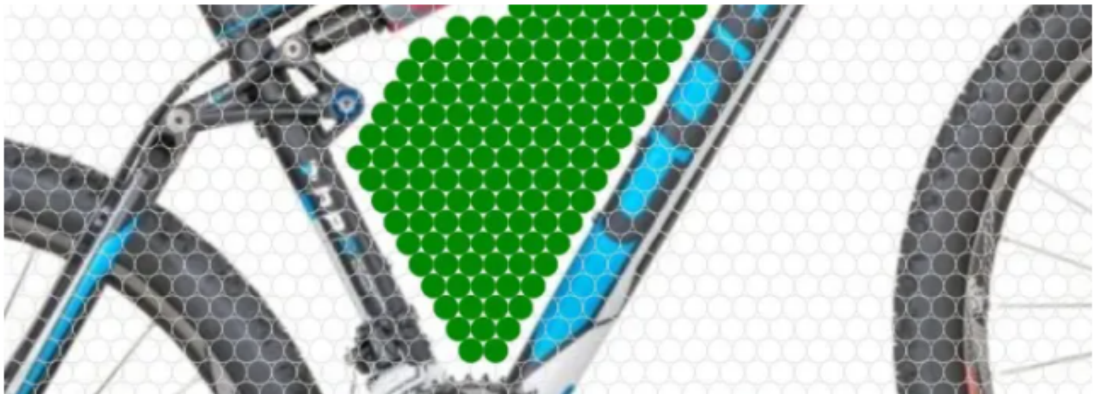
In the pic below, you can see that when using a honeycomb pattern, the side angle of the stacked cells is about 30-degrees away from the 90-degree corners in a common

Plastic 18650 assembly caps from Ann Power. The threaded brass inserts are open all the way through. Bolts to hold both ends together can be ordered in plastic, if the

common steel bolt material is a concern.

In the pic below, you can see that when using a honeycomb pattern, the side angle of the stacked cells is about 30-degrees away from the 90-degree corners in a common rectangular pack. This makes it a natural fit into the lower part of the frame triangle space. Mounting the weight of a pack low and in the center of the frame is the best place to put them, so the bike will handle well.

This pic is from a battery pack design website in Russia, and it helps you figure out how many cells can fit in your frame



This pic is from a battery pack design website in Russia, and it helps you figure out how many cells can fit in your frame

The Russian battery pack configurator program can be found here. Feel free to experiment with every possible setting to see what the setting widows do.

Triangle packs, and odd shapes

The easiest pack to design is a rectangle (as seen above). However, like the pic below, it's sometimes useful to make your pack a triangle, or some other odd shape. In the pic below, the builder is trying out a dry-fit to see how the 100 cells shown would work, and also

how the 100 cells shown would work, and also how to arrange the 5P paralleled groups which are now in odd-shaped clusters (instead of being in-line).

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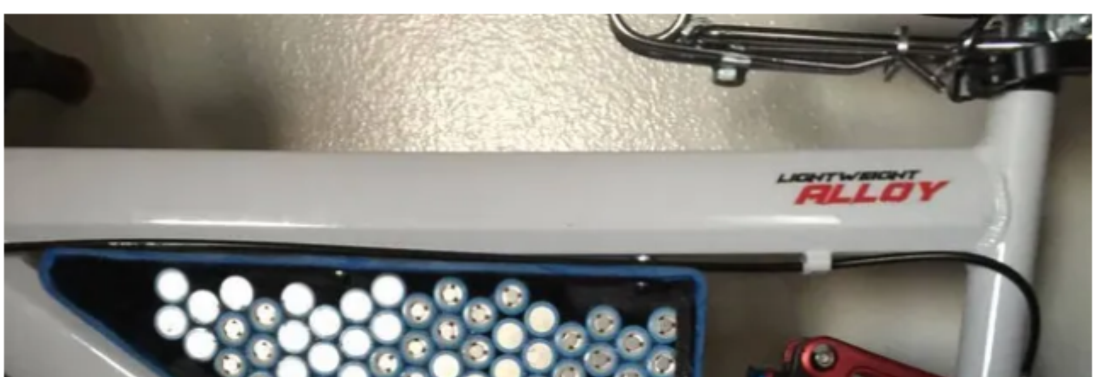

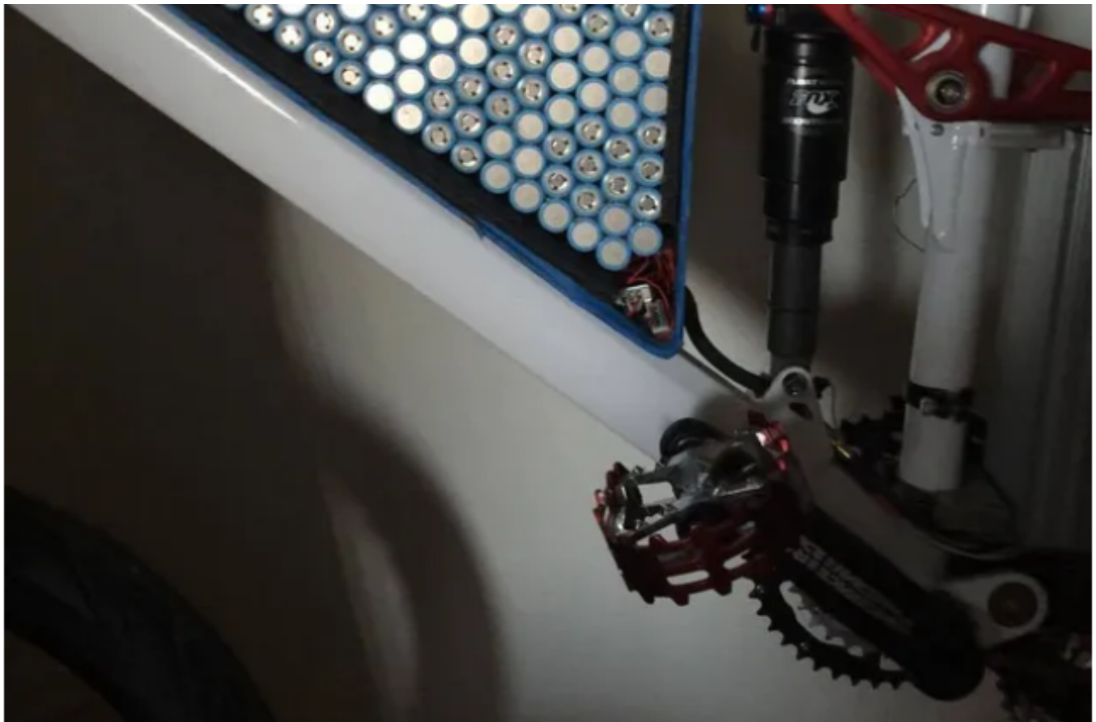

This is what 100 cells in the 18650-format look like in a bike frame triangle. This particular pack will be 20S / 5P.

Instead of using nickel ribbon to make the series and parallel connections, you can use a flat plate to accomplish all of the electrical bus functions. This 21S pack has 12P groups,

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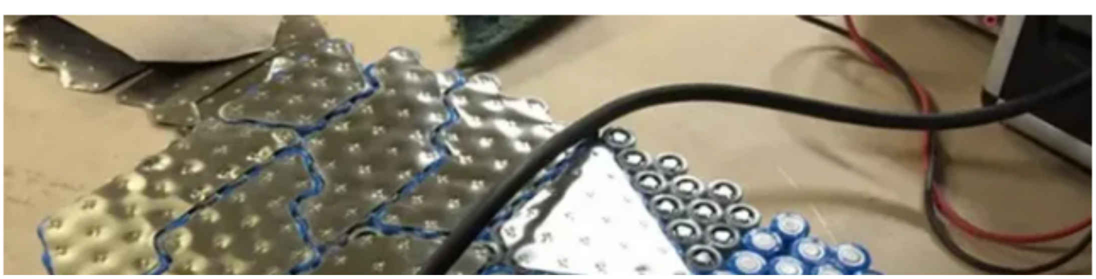

Instead of using nickel ribbon to make the series and parallel connections, you can use a flat plate to accomplish all of the electrical bus functions. This 21S pack has 12P groups, for a HUGE 252-cell pack…

The huge battery pack shown above is from Mark's Cromotor Phatrod, which can be found by clicking here.

What voltage to choose?

The actual precise voltages are approximate, but…here are the most common 18650 cell

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The actual precise voltages are approximate, but…here are the most common 18650 cell Series-counts, and the nominal voltages.

24V…7S__________52V…14S

36V…10S_________60V…16S

44V…12S_________72V…20S

48V…13S_________88V…24S (100V when fully charged)

For high amps and good range, I like the 30Q which provides 3000-mAh, and **15A**. If you want **20A** per cell, check out the Sony VTC6, LG HG2, and Samsung 25R

If your pack is big enough that you don't need the high amps of the 30Q, you can get more range by choosing one of the popular **10A** cells, which are generally rated at around

3400-mAh. Three examples are the Samsung

If your pack is big enough that you don't need the high amps of the 30Q, you can get more range by choosing one of the popular **10A** cells, which are generally rated at around 3400-mAh. Three examples are the Samsung 35E, LG MJ1, Panasonic GA (a few months after any article is published, there may be even more options to compare, so do your homework before buying)

I like 48V and 52V for a variety of reasons. If you went to a higher voltage, it would require more parallel groups to be added to the series string to raise the volts. It would be easy to quickly end up with a design that is large, heavy, and expensive. Years ago, there were few options when it came to how many amps the 18650 cells could put out, so the only option for high performance was from high volts.

That being said…the more volts you use, the fewer amps you will have to pull from the pack to get the performance that your throttle is demanding.

That being said…the more volts you use, the fewer amps you will have to pull from the pack to get the performance that your throttle is demanding.

Now…there are 18650-format cells that can put out 20A, but they are pricey, and the 30Q is popular for a reason. It can put out 15A, so a relatively small 4P pack can put out 60A. A 13S / 48V pack using 4P would be only 52 cells, and it would have 12-Ah of range. Efficient mid-drive systems can get up to 2 miles per Ah, so 12-Ah could result in over 24 miles of range.

As far as going to a lower voltage than 48V/52V, if you live where it's fairly flat, then you might get acceptable performance from 36V (10S). A 4P pack of 10S is only 40 cells! (very easy to fit). Of course, even if you don't need lots of volts, or lots of power, if you have the budget and the frame space to mount a larger battery, then the pack will run cooler. Helping the pack to run cooler will help it last as long as possible.

larger battery, then the pack will run cooler. Helping the pack to run cooler will help it last as long as possible.

One last note, an ebike battery is one of the biggest battery packs you will likely ever buy in your life. If you can accomplish your goals with a 48V or 52V pack, either one of those can power an inverter in a disaster to provide 120V AC to your home. If you use 4P of common 10A cells (40A), and the pack is 52V, then…40A X 52V = 2100W. That's enough watts to run your refrigerator and TV for quite a while. And the bigger the pack, the longer your appliances can run…

Why go to all this trouble?

In the pic below, ES member Kepler built a tiny 14S / 4P pack (52 cells) that perfectly fits his favorite ebike frame, which uses a Bafang BBS02 mid drive. In the interests of full disclosure, my favorite ebike uses a large 52V pack that I purchased from Luna Cycle.

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Kepler's "Super Commuter", with a custom home-built battery pack made from 18650 cells.

Part-2

Once you have decided on the voltage, the size, and the shape, I'll be covering a lot of things in part-2 (click here), and among them are all the popular methods for connecting the cells to each other, such as spot-welding and wire-bonding (add link to part-2 here)…

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If you liked this article, you might also like…

"What's inside an 18650 cell, and why it's important"

"BMS's, what the hell do they do?"

"A Home-Built Ebike battery pack from 18650 cells"

Send suggestions, corrections, and death threats to: Prisoner #41, Kansas state correctional facility for the criminally insane.

Written by Ron/spinningmagnets, February

Written by Ron/spinningmagnets, February 2019

More

78% 2:52 PM

HOW TO BUILD YOURSELF

Introduction to battery pack design and building, Part-2

March 30, 2019 8 Comments
How To Build Yourself Spinningmagnets

If you are new to battery-pack building, but you are also a pretty capable fabricator, this article will define some of the common materials and methods that are popular so you can decide what would be best for you

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If you are new to battery-pack building, but you are also a pretty capable fabricator, this article will define some of the common materials and methods that are popular so you can decide what would be best for you.

Understanding 18650 cells

In part-one of this series, I put out the best argument I could in order to explain why 18650 cells are the most popular for building an ebike battery pack (for part-1, click here), and we also wrote about what is inside 18650 cells (to review that article, click here). If you haven't seen those articles yet, I highly recommend you take a quick look at them before moving on to this article.

The two electrodes of a standard 18650 cell. The bottom and sides of the shell are the negative electrode, and it also provides compression to the jelly-roll, and some modest physical protection against small bumps.

In the pic above, you can see that the positive end of an 18650 cell is a metal disc with a raised central nipple. The black high-temp rubber insulator just below it is the part that separates the positive from the negative.

Car batteries have a wide separation between the positive and the negative electrodes of a lead-acid starter battery (with a plastic case), but...on an 18650, the entire bottom and

Car batteries have a wide separation between the positive and the negative electrodes of a lead-acid starter battery (with a plastic case),

but…on an 18650, the entire bottom and sides are the parts that are charged with the negative. It may have thin PVC “heat shrink” sleeve over the sides, but…this is by far the most important fact to remember when designing a pack out of this type of cell.

On the left, the builder is adding a fiber insulation washer (self adhesive) to the positive end, which is the dark green part, and on the right a plastic cap is also added. I would do both.

In the pic on the left above, the 18650 cell has a light-green PVC heat-shrink sleeve over the sides. And underneath the positive end is an white plastic washer as additional insulation. You may think that this is enough layers of would do both.

In the pic on the left above, the 18650 cell has a light-green PVC heat-shrink sleeve over the sides. And underneath the positive end is an white plastic washer as additional insulation. You may think that this is enough layers of safety insulation between the positive and negative in order to prevent a "shoulder short" that might be caused by heat and vibration wearing through the PVC sleeve. I would never consider building a DIY pack without first adding the dirt-cheap fiber washers as additional insulation.

A shoulder short. Fortunately, this one was just a giant spark with some melted plastic sleeve, and didn't escalate into a fire. Pic courtesy of Offroader.

In the pic above, the cells were "hot glued" into a tight honeycomb formation. I am not a fan of hot-gluing. The heat from a cell getting too hot can partially melt away the PVC sleeve, and if that happens? the hot glue is no longer holding the cell in its place. When that happens, the weight of the cell during a pothole hit and also during road vibration, will

fan of hot-gluing. The heat from a cell getting too hot can partially melt away the PVC sleeve, and if that happens? the hot glue is no longer holding the cell in its place. When that happens, the weight of the cell during a pothole hit and also during road vibration, will have its force transmitted through the electrical connections.

Whether spot-welded or soldered, or whether fused or wire-bonded, the electrical connections should never be forced to bear any weight or strain.

An 18650 cell that got so hot that it melted away the PVC plastic sleeve that covered the sides.

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An 18650 cell that got so hot that it melted away the PVC plastic sleeve that covered the sides.

Bus Shape

Bus Shape

I've shown the series and parallel connections that used common nickel ribbon, and also single-layer plates that performed both functions. If you look at common factory-built packs, they often use a type of bus that I am going to call the "ladder style".

It will likely be a single layer of pure nickel that was laser-cut (instead of nickel-plated steel, or nickel-plated copper). This kind is "acceptable" for average amps. If we use a pack that is built like this for 25A peaks (which would be average for an ebike commuter), then each cell would provide 5A peaks during acceleration.

If these are 3400-mAh cells (rated for 10A peaks), then the pack capacity would be (5P X 3.4-Ah =) 17-Ah of range. I chose this pic as an example, because it is very "average" and common

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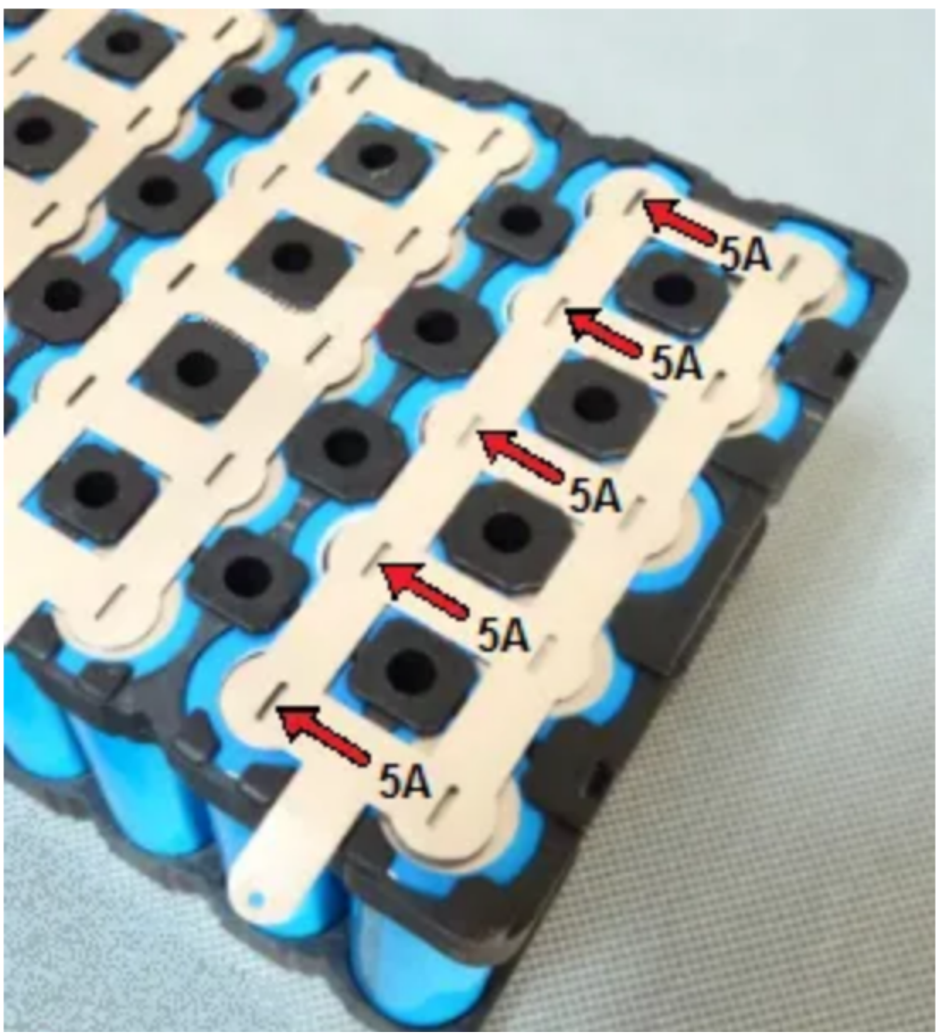

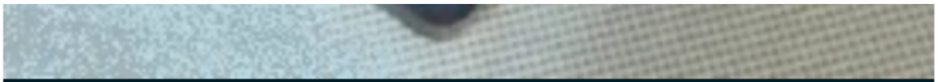

The series current flow in a 5P pack that puts out 25A. The tab at the bottom-left is the BMS connection for both the first and second row of paralleled cells. Farther below in this article, I will discuss adding copper over

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8

The series current flow in a 5P pack that puts out 25A. The tab at the bottom-left is the BMS connection for both the first and second row of paralleled cells. Farther below in this article, I will discuss adding copper over the series connections. The five short strips that are labeled "5A" (with red arrows) are where the copper would go.

Notice that the long parallel run across 5 cells, is the same width and thickness as the five short 5-Amp series runs. There is nothing “wrong” with the parallel connections being larger than necessary, but be aware that all the parallel bus is doing is equalizing each 5-cell group to act as one large cell (in this case,

short 5-Amp series runs. There is nothing “wrong” with the parallel connections being larger than necessary, but be aware that all the parallel bus is doing is equalizing each 5-cell group to act as one large cell (in this case,
a large single 17-Ah cell that puts out a nominal 3.7V).

As each cell is charged and discharged, the paralleling current on that section of the bus will be very small, and certainly less than 1A under all conditions. I point this out to help builders make decisions about all the possibilities for viable options.

For the parallel current, nickel is the perfect material. It spot-welds easily, and its significant resistance prevents current from moving too rapidly between the cells. When considering what ribbon to use for the **series** connections of a higher-amp pack, most builders will increase the bus ribbon mass by using something thicker, like 0.20mm instead of 0.15mm (or even using two layers of 0.15mm thick nickel ribbon)

moving too rapidly between the cells. When considering what ribbon to use for the **series** connections of a higher-amp pack, most builders will increase the bus ribbon mass by

using something thicker, like 0.20mm instead of 0.15mm (or even using two layers of 0.15mm thick nickel ribbon)

However, for the **parallel** connections, there is nothing wrong with using the thinner ribbon. In fact, the common width of the ribbon shown above is roughly 8mm wide (to fit into the tracks of the common black plastic cell-holders), and you can slice that to a 4mm width for the parallel connections, without causing any performance problems.

When contemplating higher amps, some builders will spot-weld a second layer of nickel ribbon over the first series connection layers. However, I am not a fan of that approach. No matter how thick you make the nickel on the series connections, that material still has poor conductivity. Any heat in the buses is “waste heat” (it’s not performing any work), and making the series buses out of nickel on the series connections, that material still has poor conductivity. Any heat in the buses is “waste heat” (it’s not performing any work), and making the series buses out of thicker nickel only spreads the heat out to prevent a fire. Thick nickel buses in a high-amp pack will have lots of voltage drop across the connections, and that hurts performance.

Guess what material is used in the coiled wire that forms the heating element in a hair dryer or an electric clothes dryer?…it’s nichrome wire, which is 80% nickel. This is because the high resistivity of nickel converts the watts flowing through it into heat (plus it has low oxidation). The characteristic of heating up from current is what makes nickel very easy to rapidly spot-weld. It’s also desirable due to its resistance to corrosion, but…it’s high-resistivity / low-conductivity is what makes it barely adequate as a conductor.

The pic below is made up of red-sleeved

18650 cells in a 10S / 4P configuration…At this point, the builder has spot-welded the series connections, but there are no parallel

The pic below is made up of red-sleeved 18650 cells in a 10S / 4P configuration…At this point, the builder has spot-welded the series connections, but there are no parallel connections yet. It may sound odd, but this pack would work fine "just like this" with no parallel connections. It would likely take a few charge/discharge cycles before the individual cell voltages began to get seriously out of balance (with no parallel connections).

A 10S / 4P pack. The only connections that are spot-welded at this point are for the series current.

The second thing I want you to notice about the red pack above is that the builder made the series connections first. Most builders feel that it is easier to make the parallel connections first, and it probably is. However

the series connections first. Most builders feel that it is easier to make the parallel connections first, and it probably is. However,
that means that the higher series current from each cell must pass through the parallel strip in order to reach the series strip. This isn't horrible for a low current pack (low performance), but remember…for high amps, any added layers will definitely cause more resistance, hot spots, and voltage drop.

I also want to point out, this builder used the additional fiber insulation washers on the additional fiber insulation washers on the positive tips (dark gray), and he also did not spot weld onto the center of the negative ends (see below).

A 20S / 7P pack. The positive/negative series-end collectors are the seven yellow wires at each end. Those 14 wires will be bundled into a large red and black cable set.

A 20S / 7P pack. The positive/negative series-end collectors are the seven yellow wires at each end. Those 14 wires will be bundled into a large red and black cable set.
Pic courtesy of bigbore in Italy.

The pic above shows a 20S / 7P pack. Notice that the parallel strips are on TOP of the series strips, so they won't interfere with the series-strips being able to flow the max possible amps, with the minimum amount of waste-heat. Also notice that the parallel strips are narrower, simply because wider strips are not necessary.

The last thing to pay attention to is that…for every two "series connected" 5-cell P-groups, there only needs to be one parallel strip on each end. If you review part-1, you'll see this in the section on how to wire up a BMS. If the factory bus-plates (a few paragraphs above) are shaped like a ladder (with two long parallel runs on each side of the paralleled cell-groups), the latest trend is to use nickel ribbon to form buses with a "comb" shape. Having a ladder shape to the bus with two

in the section on how to wire up a BMS. If the factory bus-plates (a few paragraphs above) are shaped like a ladder (with two long

parallel runs on each side of the paralleled cell-groups), the latest trend is to use nickel ribbon to form buses with a “comb” shape. Having a ladder shape to the bus with two paralleling strips per end doesn’t hurt, but…it also doesn’t help.

If you decide that this is the method you want to use, I recommend that you avoid making additional connections around the positive “nipple” (which is the danger zone for shoulder shorts), so I would attach the parallel-current nickel ribbons across the negative ends, just like the pack shown above…

Positive and Negative Bus Collectors

The pic below shows an 8S / 5P pack (a nominal 28V), and since it is an even number of cell groups, the positive and negative ends

are both on the same side of the pack (the

The pic below shows an 8S / 5P pack (a nominal 28V), and since it is an even number of cell groups, the positive and negative ends are both on the same side of the pack (the narrower strips on the left and on the right). The bottom of this pack would have four of the larger “2S/5P” plates. This pack uses plates instead of strips to accomplish both the parallel and series connections.

An 8S / 5P pack, pic courtesy of rojitor in Spain

In the pic above, the thin strip on the left is the positive for the entire pack, and the thin strip on the right is the negative for the whole pack.

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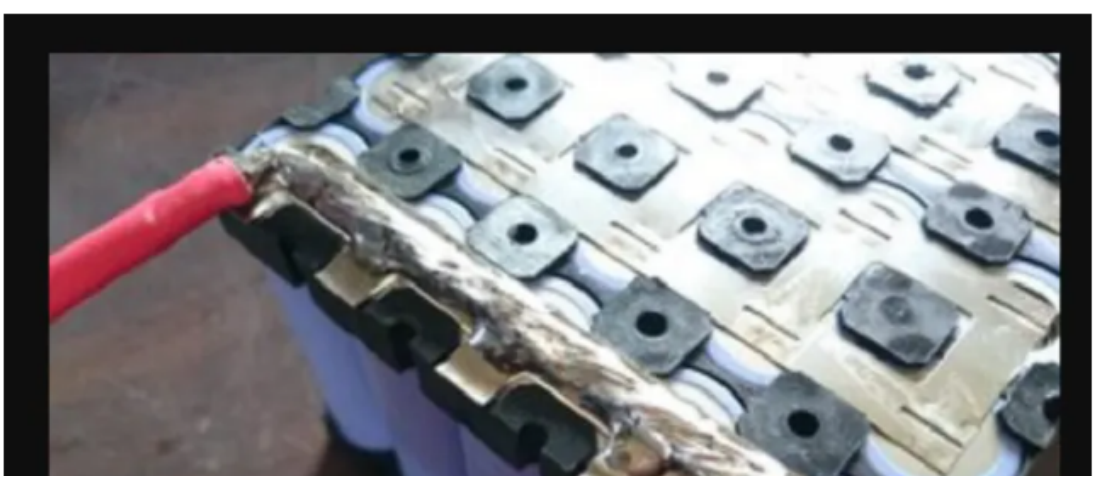
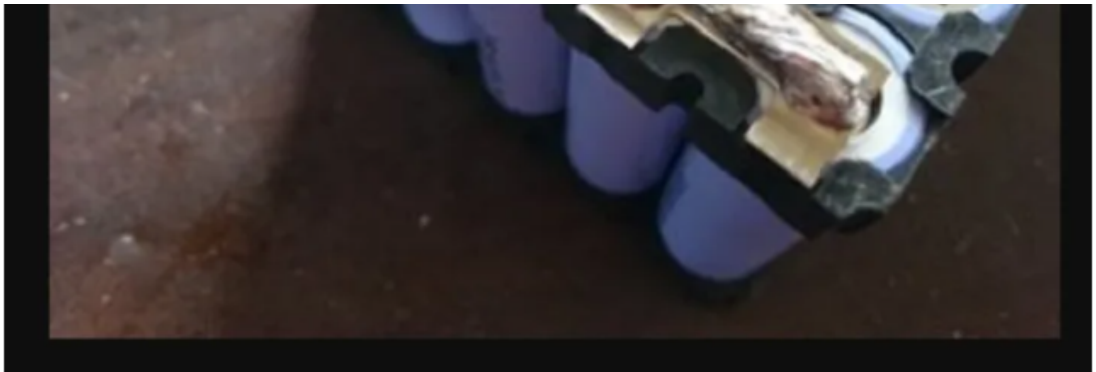
Spain

In the pic above, the thin strip on the left is the positive for the entire pack, and the thin strip on the right is the negative for the whole pack.

The pic below shows a thick copper wire soldered over the entire positive end of the pack bus-ribbon, and then that row of nickle ribbon has been folded over.





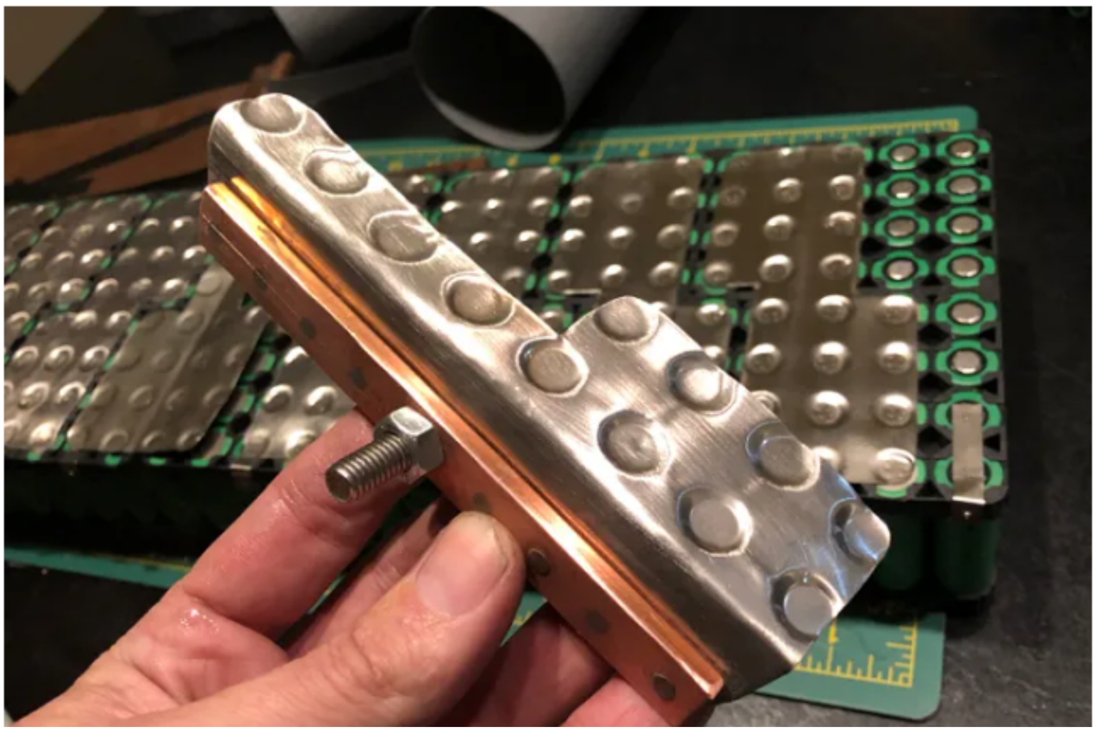
A 5P pack, with a large copper wire soldered over the end collector on the positive end of the pack. Pic courtesy of flangefrog in New Zealand.

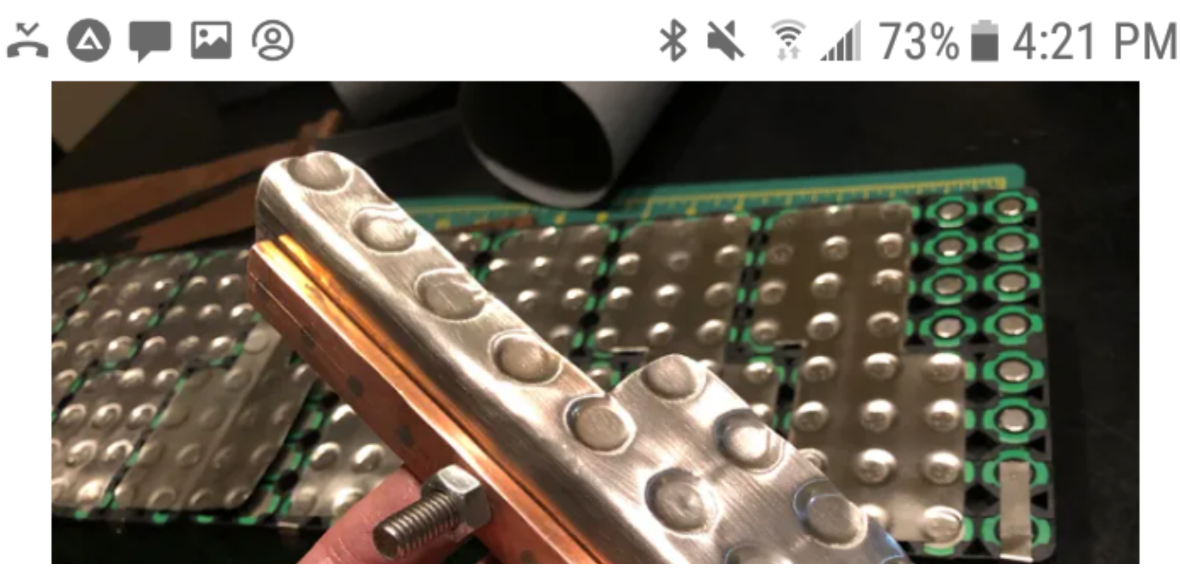
If the two paralleled strips on each end don’t have any added connective layer, some of the

A 5P pack, with a large copper wire soldered over the end collector on the positive end of the pack. Pic courtesy of flangefrog in New Zealand.

If the two paralleled strips on each end don’t have any added connective layer, some of the
cells will be farther away from connection point of the the positive/negative cable end (connecting the fat red wire at just one point on the 5P group), compared to the other cells

in that P-group. To prevent unnecessary resistance and voltage drop, the builder for the pack above has soldered a fat copper wire over the top of the entire P-strip for the end-collector.





One of the two copper end-collectors (this one is for the positive end of the 12P battery pack)

Since the paralleled groups shown above are 12 cells, then the amp-draw from each cell will be low. In that case, nickel is not a horrible material to use, but…I would have used a dremel with an abrasive disc to cut spot-welding slots (see below), and after assembly, I would have used a thermal camera to identify hot spots. Any bus location that was running warm, I would add copper wire over that spot as a jumper to reduce resistance in that bottleneck.

Copper is cheap, so this builder used a thick

that bottleneck.

Copper is cheap, so this builder used a thick copper bar as the collector. It may look like the central bolt is a conductor, but it is only used to clamp a thick copper ring connector directly to the copper collector bar (copper touching copper, the steel bolt only clamps them).

In the pic above, notice that the pack is on a plastic non-conductive mat (green). They are cheap, and if you build a battery pack, this MUST be your first purchase. Your bench may not be metal, but when building expensive high-amp battery packs, never take any chances. Every part and action must be carefully chosen and proper procedures must be followed…and this is what professionals do. Do it.

What materials to use?

Resistivity is bad, and it is the opposite of
conductivity. Resistance is measured in milli-

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What materials to use?

Resistivity is bad, and it is the opposite of conductivity. Resistance is measured in milli-Ohm's per meter of length. Copper is 16.8 (a low resistance number is good), Aluminum is 28.0, Nickel is 69.9

If you have room for a large battery pack, then you may not need to use a high-amp cell like the 30Q, HG2, VTC6, or 25R. In that case, you can use one of the popular "high capacity" cells like the GA, 35E, and MJ1, which would provide more range per volume.

Those three have a capacity of roughly 3400-

mAh each, and are frequently used with an occasional amp-draw of 8A. If that sounds like a pack that would fit your needs, you might as well use common 0.20mm thick nickel ribbon as the series connections. That style of ribbon is common and affordable, and it spot-welds easily with the common models of welder (see

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below).

However, for high-amp cells (15A-30A each) the Makita buses are a good example, and their cordless tool batteries use nickel-plated copper as the bus-plates. The nickel-plate copper as the bus plates. The nickel plate allows common spot-welders to make the connections, but the copper core provides low resistance and high conductivity, so the high amps drawn by the tool do not cause the bus to get hot.

If any of the electrical connections are getting hot during normal use, they are converting battery watts into waste-heat (plus a hot spot indicates a bottleneck to current). Also, hot connectors have a higher resistance than the same connectors when they are cool, so the

If any of the electrical connections are getting hot during normal use, they are converting battery watts into waste-heat (plus a hot spot indicates a bottleneck to current). Also, hot connectors have a higher resistance than the same connectors when they are cool, so the hotter they get the worse the efficiency becomes. If an electrical connection is hot during normal use, it will cause a voltage drop.

You must either make the connector larger, or use a more conductive material (a material that has less electrical resistance)…or both.

The IACS List

The conductivity of the materials listed below are all compared to copper, and it is called IACS, for the International Annealed Copper Standard. On this scale, Copper is 100 out of 100, Aluminum (6061) is 43/100, and Nickel is 23/100. Below is a list of the IACS conductivity of every material that we might be interested in, starting with the most conductive at the top, and the worst at the bottom.

23/100. Below is a list of the IACS conductivity of every material that we might be interested in, starting with the most conductive at the top, and the worst at the

bottom.

106 Silver (Ag) This is the best conductor that's not some exotic material, but it's expensive. Anderson Power Pole connectors that are authentic have contacts that are silver-plated copper. Silver is subject to "some" oxidation, but it's not bad. Any oxidation (tarnish) is easily cleaned. Andersons depend on the "wiping" action of the connector being inserted to clean the contacts, and apparently that is OK for most applications.

100/100 Copper (Cu). A great electrical conductor and affordable. Unfortunately it also oxidizes easily (corrosion), and this is especially bad near the ocean, due to the salt in the air. The copper-oxides that form are the "green cancer".

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Here is a strip of copper, and a strip of aluminum, and both have been outdoors in the weather for some time. The left sides are still oxidized, and the right sides have been sanded to a shiny clean surface.

93 Tellurium Copper-C14500. Pure copper is soft and difficult to machine (I have personally broken many drill bits in pure copper). This alloy still has 93% of the conductivity of pure

copper, but is much easier to drill, mill, or cut on a lathe. Good for making thick electrode holders used for spot-welding. Click here for one supplier option that I have used with

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76 Gold (Au). Gold is only a “fairly good” conductor, but it is VERY resistant to oxidation and corrosion. This is why many connector types have a very thin plating of gold on them (like connectors from Hobby King).

65 Aluminum-Pure (Al), 1/3rd the weight by volume, compared to copper. Higher electrical resistance than copper, so conductors must have more cross-sectional area compared to copper. Difficult to solder or spot-weld. Metal retailers don't often carry **pure** aluminum, so **do not use the 65/100 conductivity number** for all practical purposes. Aluminum easily

have more cross-sectional area compared to copper. Difficult to solder or spot-weld. Metal retailers don't often carry **pure** aluminum, so **do not use the 65/100 conductivity number** for all practical purposes. Aluminum easily
forms a thin oxide layer when exposed to air. However, no matter how thin, this type of oxide is very resistant to current.

Tesla uses aluminum bus-plates and fuse-wire, but the surfaces are specially prepared and and then immediately bonded. Any oxide layer that forms will only be on the skin AFTER the wire-bonding is done (see below)

61 Aluminum-8176 (8000-series has added Fe + Si). IACS-61 is a lower number than 65 (for pure Al), but…you can actually buy 8176 alloy. It is used for aluminum electrical wire.

43 Aluminum 6061-T6. The 6000-series has added Mg + Si. This alloy welds, cuts, and drills easily. It can be readily found as plate, bar, rod, etc. If you go into a store that carries any kind of aluminum, they will have 6061. If you use aluminum as a conductor (like the two pack

43 Aluminum 6061-T6. The 6000-series has added Mg + Si. This alloy welds, cuts, and drills easily. It can be readily found as plate, bar, rod, etc. If you go into a store that carries any kind of aluminum, they will have 6061. If you use aluminum as a conductor (like the two pack
collectors), you should use 6061, then double

the thickness, and then add another 10% of thickness (compared to a minimum-sized copper collector). Click here for one supplier option that I have used with success.

31 Tungsten (W). This metal has a VERY high melting temperature, so when using it as a spot-welding tip, it will not soften and stick to the work-piece. However, it's low conductivity also means that when using high spot-welding amps, it will get very hot. Rods can also be found that are half Tungsten and half Copper, so they cost less and don't get quite as hot. One strategy is to make a fat electrode out of tellurium copper (see above) and only use Tungsten at the very tip that contacts the work.

33 Aluminum 7075-T6. This alloy is very

quite as hot. One strategy is to make a fat
electrode out of tellurium copper (see above)
and only use Tungsten at the very tip that

contacts the work.

33 Aluminum 7075-T6. This alloy is very common, but I don't recommend it (as a conductive bus collector material), except you might possibly use it as part of the housing framework around the battery. It is as hard and as strong as mild steel, but lighter and also more expensive. The 7000-series of alloys has some Zinc added.

28 Brass-yellow (copper with 25% zinc). This is the common and affordable type of brass. Yellow Brass occupies an interesting middle ground on this list. It is more conductive than nickel, but that also means that it is slightly harder to spot-weld, although that is certainly do-able. It solders easily. It is not quite as resistant to corrosion as nickel, but it is MUCH more resistant to corrosion than copper. Brass should make a very viable and affordable pressure contact (for no solder/no weld, see below).

weld, see below).

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27 Zinc (Zn). There are quite a few thick electrical connectors that are made of copper, but as a corrosion protection they often plate the connector with Zinc as a thin coating. Zinc is very affordable and abundant.

Even though any exposed Zinc will take on a dull gray color after a while, it's oxidation resistance is very good (plus the relative electrical resistance of zinc-oxide is not too bad). The 27/100-conductivity number is definitely "poor", but as long as the plating is thin, it should not add very much resistance.

23 Nickel (Ni). I was shocked when I first saw how nickel's conductivity is this poor, since I

already knew how often it is used as a conductor on ebike battery packs. However, if you use nickel “only” as a plating material that is thin, it’s resistance is minimized. The high-amp bus plates in Makita cordless tools are a

23 Nickel (Ni). I was shocked when I first saw how nickel’s conductivity is this poor, since I already knew how often it is used as a conductor on ebike battery packs. However, if you use nickel “only” as a plating material that is thin, it’s resistance is minimized. The high-amp bus plates in Makita cordless tools are a copper core with a nickel-plating to make spot-welding easy.

If there was a new product that I could have made available, it would be nickel-plated copper buses in the comb style (seen above).

copper buses in the comb style (seen above), and made in a long roll that could be cut to the desired length. Copper is cheaper than nickel, but the plating process of a given thickness of electric bus would make “Ni-plated-Cu” more expensive than just pure nickel buses (at least, for now at current nickel prices), but this is what high-amp 18650 cells need.

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The desirable features of pure nickel (as a bus material) are that it has a very high corrosion resistance, and also that it spot-welds very easily. Over the past decade, the majority of ebike battery packs from China have been spot-welded by high-speed assembly-line robots, which is fine for low-amp cells.

15 Tin (Sn). My favorite electrical solder is 63% Tin (and 37% Lead, Sn/Pb). It solders easier than any other version I've found. However, I was shocked by how poor of a conductor it is (and it's Lead partner is even worse). However, an often unappreciated characteristic of solder is how it pneumatically seals copper-wire joints away from air and oxidation. Covering anything with a thin coat of solder is called "tinning".

conductor it is (and it's Lead partner is even worse). However, an often unappreciated characteristic of solder is how it pneumatically seals copper-wire joints away from air and oxidation. Covering anything

with a thin coat of solder is called "tinning".

13 Solder-SAC305 (96% Tin, 3% Silver, 0.5% Copper…SAC = SnAgCu). Ever since the RoHS act (Reduction of Hazardous Substances), there was a drive to create a workable “lead-free” solder. It is 96% tin, and it is horrible to solder with, plus it requires much higher heat. SAC305 is the most common industrial lead-free solder. Industrial fuse-wire has a very similar composition to SAC305.

12 Solder-63/37 (Sn/Pb). This is the best solder for any electrical connection, but it should be kept as thin as possible between the two joined elements to minimize its resistance, because it is actually a poor conductor (12/100…WHAT?!). Solder called 60/40 is almost identical.

11 Steel (don’t laugh). The positive and

two joined elements to minimize its

resistance, because it is actually a poor conductor (12/100…WHAT?!). Solder called 60/40 is almost identical.

11 Steel (don't laugh). The positive and negative electrodes on the 18650 cells are nickel-plated STEEL. That's right, there is a conductor in the series current that is steel. But…I suspect most of the voltage takes the path of least resistance, and actually passes through the nickel-plating.

7 Lead (Pb). Lead is abundant and cheap. It is the alloy in 63/37 Tin-solder, and it is also the connector posts in most car-starter batteries. However, it is another horrible conductor with an IACS conductivity of 7/100. If it took more than one second to start your car (200A is common), the lead posts would get VERY hot.

3 Stainless Steel. Steel is 99% Iron with 1/3rd of one per-cent of carbon. Stainless adds

some Chromium for corrosion resistance. I
have seen fuse-wire made of stainless,

is common), the lead posts would get VERY hot.

3 Stainless Steel. Steel is 99% Iron with 1/3rd of one per-cent of carbon, Stainless adds some Chromium for corrosion resistance. I have seen fuse-wire made of stainless, because it doesn't rust away over time, and it spot-welds easily. However, it's more of a resistor than a conductor. However, stainless wire could be used as a paralleling strip.

Soldering

I'm going to make a few broad statements that might be be controversial. First, I am stating that it's not horrible to solder a connection onto the **positive** nipple of an 18650 cell. As onto the **positive** nipple of an 18650 cell. As far as damage to the cell, if you are using the right tools and techniques, no heat damage can migrate far enough into the cell to hurt the jelly-roll. See our article on the internal construction of an 18650 cell by clicking here.

That being said, **with the wrong tools and the**

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That being said, **with the wrong tools and the wrong techniques**, you can damage the interior “jelly roll” by soldering onto the positive end.

The "right tools" are a soldering iron that provides over 100W of heat, and has a thick chisel tip in order to provide thermal mass. By that I mean…a small tip (no matter how hot) will start to cool down rapidly as soon as it touches the cell. The key factor is that a good soldered joint must be accomplished **FAST**. If you use a lower-powered soldering iron and hold it on a long time, it gives the heat some time to penetrate deep into the cell. Solder needs **188 C** (370 F) to melt, but…the electrolyte that is just inside the edge of the jelly roll only needs to get to **60 C** (140 F) to

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you use a lower-powered soldering iron and hold it on a long time, it gives the heat some time to penetrate deep into the cell. Solder needs **188 C** (370 F) to melt, but…the electrolyte that is just inside the edge of the jelly roll only needs to get to **60 C** (140 F) to be damaged,

You NEED to use good flux on a surface that has been properly cleaned just moments before attempting to solder onto the positive cell tip.

You NEED to use good flux on a surface that

has been properly cleaned just moments before attempting to solder onto the positive cell tip.

Four soldering irons I have. From left to right is small 40W unit, then a 75W Weller, My favorite 100W (with a fat tip), and last is the 200W plumbers soldering iron I found at an antique shop for $5. It has a super-fat copper tip that I can file into any shape I might need.

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In the pic above, the soldering iron on the left is a common 40W style with a tiny “pencil tip” for getting into tight spots on a circuit board, but I rarely use it for anything. The next one over is a transformer-based pistol-grip 75W unit from Weller. The wattage might have been OK for ebike connectors (connecting XT90 connectors to 12-ga wire), but the tip turned out to be too small (as soon as it touches anything, it cools down too fast).

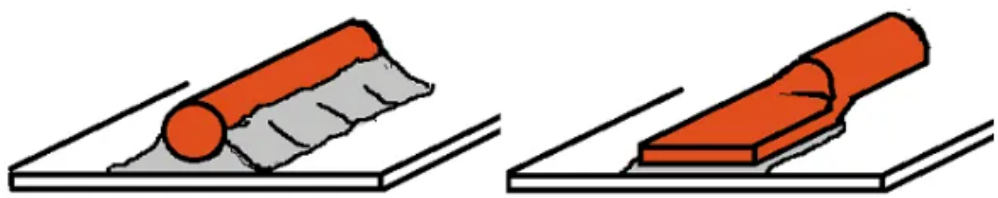
The third one over is my “go to” soldering iron for ebike jobs. It’s a cheap 100W unit made for assembling stained glass windows from a

hobby supply. The steel tip is a fairly fat chisel shape. The giant soldering iron on the right is a 200W unit that was made for a plumber to solder copper pipe. I haven’t used it for

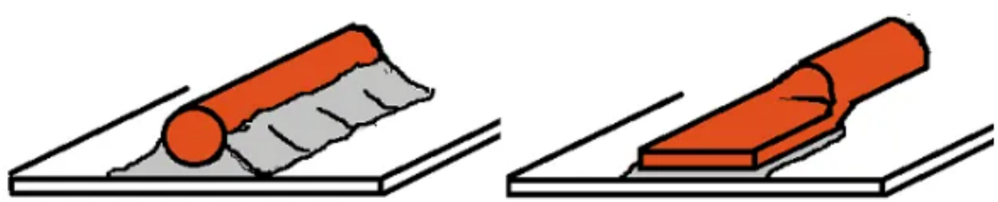
The third one over is my “go to” soldering iron for ebike jobs. It’s a cheap 100W unit made for assembling stained glass windows from a hobby supply. The steel tip is a fairly fat chisel shape. The giant soldering iron on the right is a 200W unit that was made for a plumber to solder copper pipe. I haven’t used it for anything, but it was cheap at an antique shop, and it’s here if I ever need it.

Which brings us to the **negative** end of the 18650 cell. There is not much inside the negative end to protect the jelly roll from being hurt by heat (drain an old cell down to zero and cut it open for yourself, don’t trust what anyone says, even me). **I simply cannot**

recommend that anyone solder anything onto the negative end. If you know someone who has done this and their house has not burned down, good for you. I STILL don't recommend it.



it.



Solder is a poor conductor, and it has high resistance. However, if you MUST solder, the broad cross-section of the flattened wire shown on the right has much less resistance than the solder on the left, due to the solder being thin. The flattened copper wire on the right will also solder much faster. USE FLUX when you solder!

In the graphic above, I am showing the difference between a round cross-section of copper wire that is soldered onto an 18650 cell tip (nickel-plated steel), or possibly a nickel bus-ribbon...and then the same joint, if you flatten the copper wire tip.

A flat rectangular cross-section of a given wire (seen in the pic above) will flow the same amps as a round cross-section of wire, if the two cross-sections of both have the same area. This is why electrical engineers use the

A flat rectangular cross-section of a given wire (seen in the pic above) will flow the same amps as a round cross-section of wire, if the two cross-sections of both have the same area. This is why electrical engineers use the
area of the cross-section in millimeters-

squared (mm2) to calculate the proper size of a conductor.

For instance, the common plastic cell holders have an 8mm wide slot, so the common nickel bus-ribbon is 8mm wide. The various nickel ribbons are then distinguished by their thickness. The common thicknesses are 0.15mm and 0.20mm. This means the cross-sectional area of those ribbons are 0.15mm X 8mm = **1.2mm**-squared, and 0.20 is 0.20mm X 8mm = **1.6mm**-squared.

If you wanted to add some affordable and thin copper sheet over the series connections of the nickel buses, the 15A-to-20A of the high-current 18650 cells (25R, 30Q, HG2, VTC6, etc) can be easily handled by 30-ga copper sheet (8mm wide).

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Here is a chart to compare the cross-sectional area of a copper conductor in mm2 (round wire, bar, sheet) can be found by clicking here. Sheet Metal "gauge" thickness is different than wire diameter gauge. Below, I am listing the common copper sheet gauges so you can decide what to get if you want to experiment with adding copper sheet over the nickel ribbon.

[one-mil is 0.001-inch thick, when researching sheet-metal options]
0.15mm__6-mil__34 ga [copper this thin will crumple like paper]
0.20mm__8-mil__32 ga
0.25mm__10-mil__30 ga [recommended for initial experiments]

0.33mm__13-mil__28 ga

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[sizes below require sheet-metal shears to cut]
0.40mm__16-mil__26 ga__12-oz per sq foot/B370 architectural 99% copper sheet
0.51mm__20-mil__24 ga__16-oz
0.64mm__25-mil__22 ga__20-oz
0.81mm__32-mil__20 ga__24-oz
1.02mm__40-mil__18 ga

The first four thicknesses shown above can easily be cut with scissors. Remember, for a given cross-sectional area, copper is over four times as conductive, compared to pure nickel. If you feel that 0.20mm nickel works fine for 10A peaks per cell, then 0.20mm copper would work for 40A per cell.

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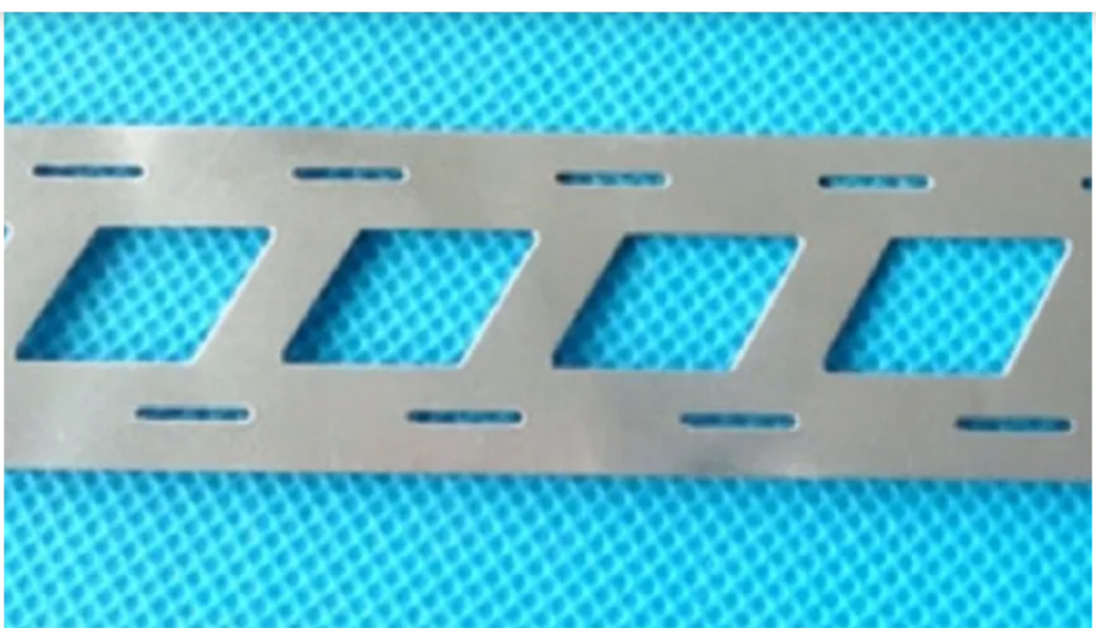
My recommended 0.25mm thick copper can be cut into 8mm wide ribbon (to match the width of common nickel ribbon for comparison), and 8mm X 0.25mm = 2mm-squared in cross-section, which is equal to 14-ga copper wire.

Spot-Welding

Spot Welding is when you send a very short pulse of high current through two pieces of metal so that they will melt together, and hopefully make a solid connection. You may have noticed that some of the nickel ribbon that is used as a bus material has a slot over each of the cell locations, and some does not.



A ladder style of bus ribbon, which is also slanted to allow it to be used in a honeycomb configuration of pack.

If the nickel ribbon has a slot, then the current is forced to travel through the cell (which is the shorter distance for the current to travel), and this can provide a solid weld with less energy (and less heat). Does spot-welding with no slot work? Yes, but when doing that, a large percentage of the current passes through the nickel strip from one welding probe to the other.

Doing that means that you need a higher

with no slot work? Yes, but when doing that, a large percentage of the current passes through the nickel strip from one welding probe to the other.

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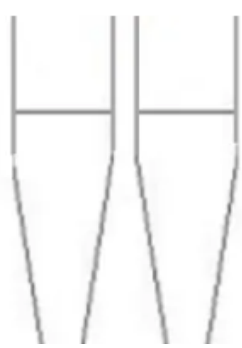
Doing that means that you need a higher amount of current to accomplish the job, which creates more heat to make the nickel melt “just enough” in the probe spots, in order to form a solid weld. Nickel melts at a VERY high 2650F (1455C). This is a lot hotter than when you are melting solder, but this high heat is only located on a tiny pair of spots, and only for a split second. As soon as the pulse stops, the rest of the surrounding metal acts as a “heat sink” to spread the heat out.

Professional pack-building companies have been adding a slot over each cell when spot-welding for years, and they wouldn’t have done it at all if it wasn’t helpful in some way.



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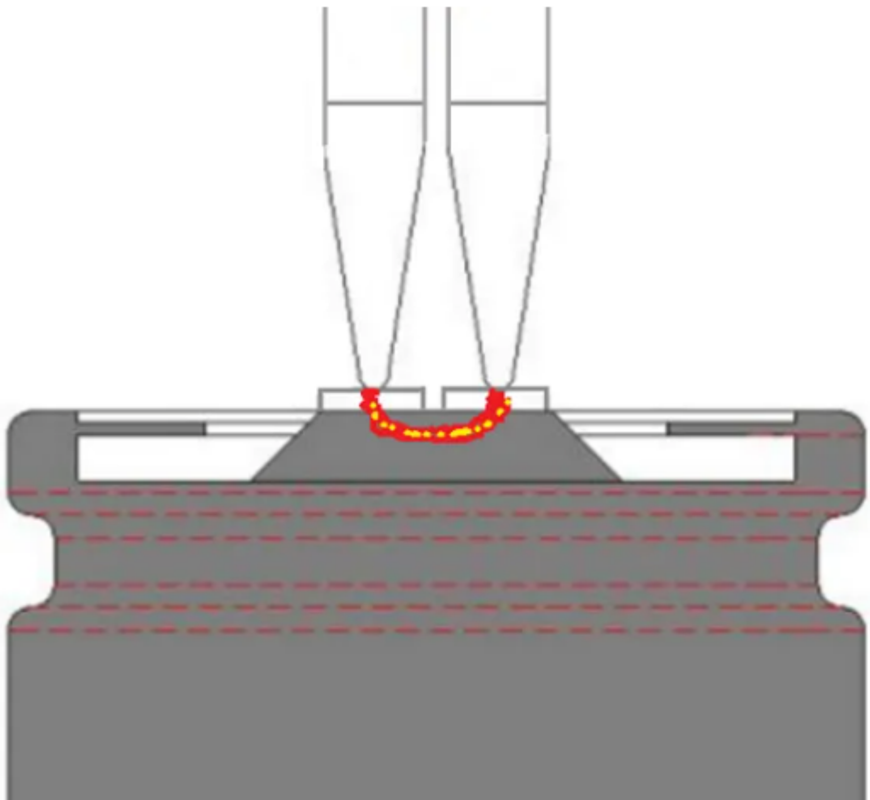
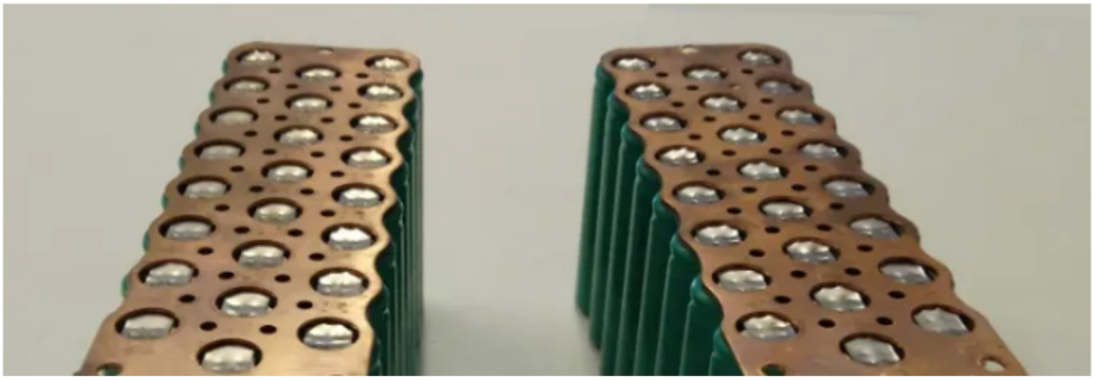


The path of the current between two spot-welding probes. The slot down the center of the nickel ribbon forces the current to go through the cell tip. The positive tip of the 18650 cell is shown.

through the cell tip. The positive tip of the 18650 cell is shown.

This is a 5S / 2P high-amp cordless tool pack from Metabo. The bus-plates are copper with a thin nickel-plating. Notice how long the slot is, between the welding points.

In the pic above, the bus-plates have a copper core with a thin plating of nickel. The nickel is easy to weld, and it also helps resist corrosion. Since copper is very conductive, this particular manufacturer uses very long slots between the weld points.



particular manufacturer uses very long slots between the weld points.

Nickel tabs on a copper bus-plate. Each of these two cell groups are 1S / 24P

Since nickel will spot-weld to 18650 cells quite easily, and copper can handle high current without causing a bad amount of voltage drop (and waste heat), why not use a copper bus-plate with a short nickel tab over the cell? I am seeing more examples of this style on electric motorcycle battery builds, which are much more demanding than ebike packs.

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You can use very high heat (and a long weld-
pulse) to bond the nickel tabs to the copper bus-plate, and *then* let it cool off before *then* using the minimum amount of energy to spot-

weld the nickel tab to the cell (you can see our article on a DIY high-amp spot-welder by clicking here). If you build an RSU you will have 700A available, and that means you don't need solder to make a bond between a copper bus and a nickel tab.

Individual Cell Fuses

A breaker is an electrical switch that automatically stops the flow of current in a circuit, when there is a burst of current that is too high. It can prevent a fire, if a circuit experiences an accidental short. However, there are many types of circuits that could use a very cheap way of breaking the complete

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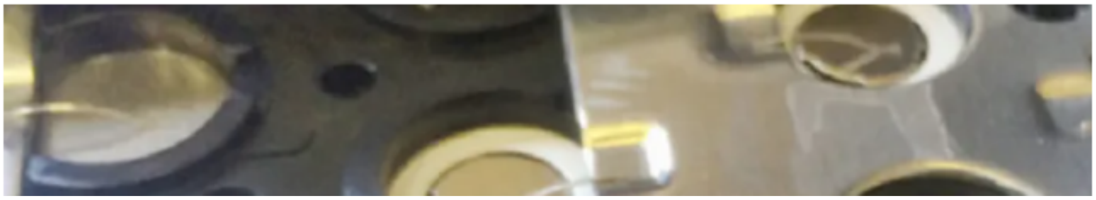
circuit, when there is a burst of current that is too high. It can prevent a fire, if a circuit experiences an accidental short. However, there are many types of circuits that could use a very cheap way of breaking the complete circuit path by inserting a short meltable conductor, called a “fuse”.

A fuse must be conductive enough to avoid causing too much resistance and voltage drop, but it must also “melt” when the current rises to its designed activation point. If one cell in a large battery pack experiences an internal short-circuit, the rapid rise in heat will melt the internal insulative separators between the anode collector and the cathode collector. When we are talking about high-amp cells, this means that the bad cell will go from suddenly hot…to possibly catching on fire.

It is bad enough when one cell is going into a death-spiral, but a cascading internal short acts as if that one cell has suddenly been

It is bad enough when one cell is going into a death-spiral, but a cascading internal short acts as if that one cell has suddenly been replaced by a thick copper wire, and now every other cell in that parallel string will be dumping its amps from their negative electrodes to the positives. For example, if you have a common 5P size of ebike pack using 30Q cells…when one of them has an internal short, then almost immediately the other four cells will be dumping their amps with almost no resistance.

A dead short of four 30Q's will kill them, and they will flow over 200A as they are dying. Once every cell in that P-group starts going wild due to the electrical connection, the heat alone can set off the all of the adjacent cells, eventually causing the entire pack to catch fire. Is there some affordable way to disconnect that one first bad cell to stop the chain of events? Yes…a fuse-wire.



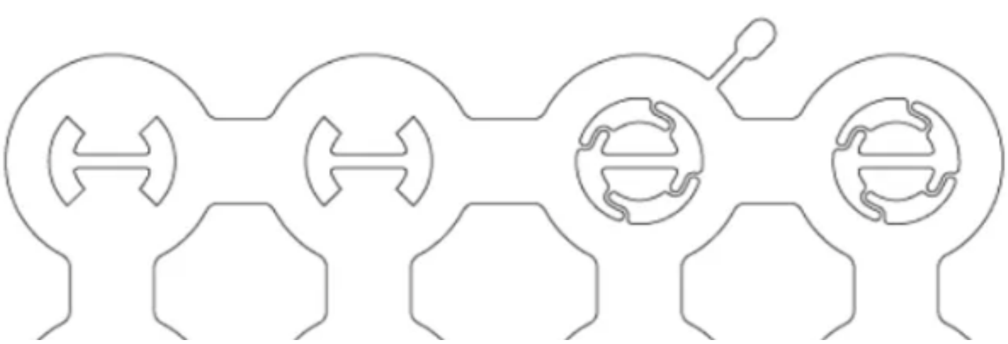
chain of events? Yes…a fuse-wire.

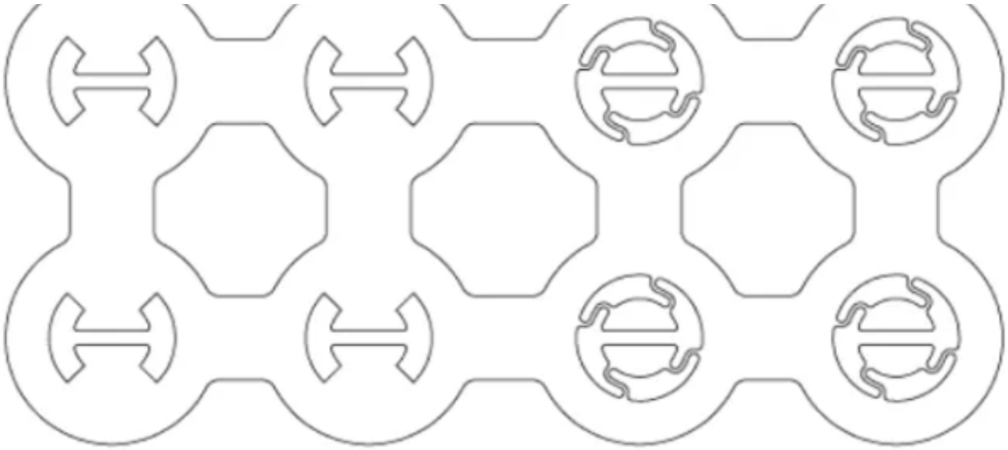
Fuse-wire on a Tesla battery pack. The three cells on the left have the negative ends up, and the five cells shown on the right have the positive electrodes pointing up. The conductive fuse-wires shown are connecting each cell-end to an aluminum bus plate.

Individual cell-fusing recently came to prominence by the Tesla car company. They did this because their electric cars could be involved in a crash, even if it wasn't the drivers fault. In the pic above, notice that even though the Panasonic cells came from the factory with a white insulation ring around each

70% 4:28 PM

fault. In the pic above, notice that even though the Panasonic cells came from the factory with a white insulation ring around each
positive cathode tip, Tesla added a thick rubber sheet over the cells as added protection.





A graphic for a laser-cut pure nickel plate that connects two 6P cell-groups in series. The six tabs on the left are for the negative ends. The six on the right are for the positives. The small tab at the top is for the BMS connection.

A fuse doesn't need to be a separate element that is connecting the bus plates to each cell. In the graphic above, the four thin strands

70% 4:28 PM

positives. The small tab at the top is for the BMS connection.

A fuse doesn't need to be a separate element that is connecting the bus plates to each cell. In the graphic above, the four thin strands
that connect the “half moon” pads on each cell

are the fuses that connect to the 18650 positive tips. There are two pads per cathode tip in order to force the welding current to travel the shortest path through the cell-tip (like the slots we discussed earlier), rather than the current just passing across the bus ribbon from one welding probe to the other.

I know this particular style ends up having FOUR integrated “fuses” per cell, but they are thin enough that calculations indicate they will work.

A fuse-wire will not stop a particular cell from experiencing an internal short, and it won’t stop the rapid overheating that would result. However, what it will do is to immediately separate that one cell from the rest of it’s P-group. Also notice that in the Tesla pack picture above, all the cells are given some air-

A fuse-wire will not stop a particular cell from

experiencing an internal short, and it won't stop the rapid overheating that would result. However, what it will do is to immediately separate that one cell from the rest of it's P-group. Also notice that in the Tesla pack picture above, all the cells are given some air-space between each other, which lessens the possibility of a hot cell starting to heat-up its neighbor.

As a final note on fuse-wire, small aircraft will often use nickel-plated copper wire, which I have just found to be readily available in 16ga and 18ga (thicker or thinner Ni-plated copper aircraft wire can also be ordered). I am about to engage in experiments where I spot-weld the strands from this wire to 18650 cells as fuse-wire. The copper core will work well for high-amp cells, and the nickel-plating should make spot-welding easy…wish me luck. I will report back as soon as I can with results.

> *AC 21-99, Aircraft Wiring and Bonding*

> *Section-2, Chapter -1*
> *Stranded conductor wire is used for*

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> *AC 21-99, Aircraft Wiring and Bonding*
> *Section-2, Chapter -1*
> *Stranded conductor wire is used for flexibility. In low temperature wire (150C), copper or copper alloy strands are tin-plated to facilitate soldering. In wire rated at 200C conductor temperature, silver plating is used to protect the copper from oxidation and to facilitate soldering. Wires for high temperatures (260C) are nickel plated to prevent oxidation. Nickel plated wire is more difficult to solder, but satisfactory solder connections can be made with proper techniques.*

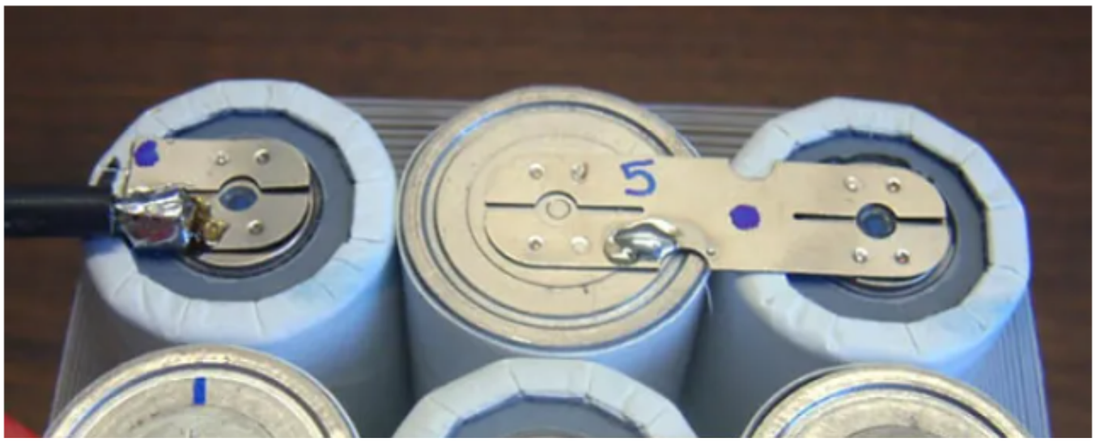
Avoid the Center of the Negative End!

I don't know why, but I have read several instruction manuals for spot-welders, and they all state that you should NOT spot-weld

Avoid the Center of the Negative End!

I don't know why, but I have read several instruction manuals for spot-welders, and they all state that you should NOT spot-weld
onto the center of the negative end. I would also suggest that nobody should ever solder onto the center (or any other part) of the negative end. I don't like soldering onto the negative end, but…if you do use solder…do NOT solder onto the center.

Below is a pic of some factory nickel strips that are spot-welded, and I saved this pic because…the factory added a “hole” in the center to make sure that no vendor can accidentally (or on purpose) weld onto the center…



that are spot-welded, and I saved this pic because…the factory added a “hole” in the center to make sure that no vendor can accidentally (or on purpose) weld onto the center…

Do NOT spot weld onto the center of the negative end of a cell. Don't solder there, as well. These factory buses have a "hole" in the center to prevent any vendor from doing that. These blue cells are in a complete 6S / 1P pack with a nominal (3.7V X 6S =) 22.2V

edit: During assembly, when the jelly roll is inserted into the negative metal shell, a probe is inserted down the center and the "tab" for the negative electrical connection is bonded

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edit: During assembly, when the jelly roll is

inserted into the negative metal shell, a probe is inserted down the center and the "tab" for the negative electrical connection is bonded to the shell at the bottom-center of the 18650 cell. If you screw around with the center of the bottom of the 18650 cell, there is a chance you might loosen the internal connection between the jelly roll and the metal shell.

Do NOT screw with the center-bottom of an 18650 shell. If you make a connection to the bottom/negative of the 18650 shell, do so off to the sides. You have been warned, so don't pretend that you didn't read this.

Kapton Tape, Boxes, and Padding

Every time you finish spot-welding a section of your pack, take the time to put some

Kapton Tape, Boxes, and Padding

Every time you finish spot-welding a section of your pack, take the time to put some insulation over it. Most builders are using Kapton tape (typically amber-colored). Kapton is made from Poly-Imide / PI, and it is a great electrical insulator (up to thousands of volts per mil of thickness).

If a part of your pack starts to get hot, Kapton will not shrivel up and make it worse (by uncovering part of the bus plates). It can accomplish this because it is very stable and heat-resistant up to 500F (260C) plus, it has excellent tensile strength (resistant to tearing from being pulled).

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This builder has just started adding Kapton insulating tape over the exposed metal. Pic courtesy of Micah Tolls battery building tutorial (click here).

A optional insulating tape that some builders are starting to use is PET (Poly Ethylene Terephthalate). It is not as heat resistant as Kapton, but at **266F** (130C), it is still excellent

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A optional insulating tape that some builders are starting to use is PET (Poly Ethylene Terephthalate). It is not as heat resistant as Kapton, but at **266F** (130C), it is still excellent
for what we are doing (I like it, a LOT)

I can't even hold my hand on 140F, and I don't recommend that ANY battery pack be allowed to reach 140F under any circumstances, so 266F is very safe for the insulation. Fans of PET tape report that it is more affordable and physically tougher than more affordable and physically tougher than Kapton.

This is a plastic NEMA outdoor