Workshop: Simon's Lithium Charger (SLiC)

What are we making?
It's a charger for rechargeable lithium-ion and lithium-ion-polymer batteries (like the phone batteries we now have in quantity at VHS). It's a highly hackable through-hole build.

Are all lithium batteries rechargeable?
No. There are also primary cells with lithium-based chemistry, such as the CR123A cylindrical type, CR1616/2016/2032 (coin cells), 2CR5 etc. These are NOT rechargeable and you should not try to do so. Also don't use this charger with non-Li rechargeables.

What's the deal with laptop batteries?
These are generally just a plastic shell enclosing a number of cylindrical rechargeable lithium-ion batteries. Often when a laptop battery goes bad, it's just one cell that has failed. The others can be rescued and used for projects.

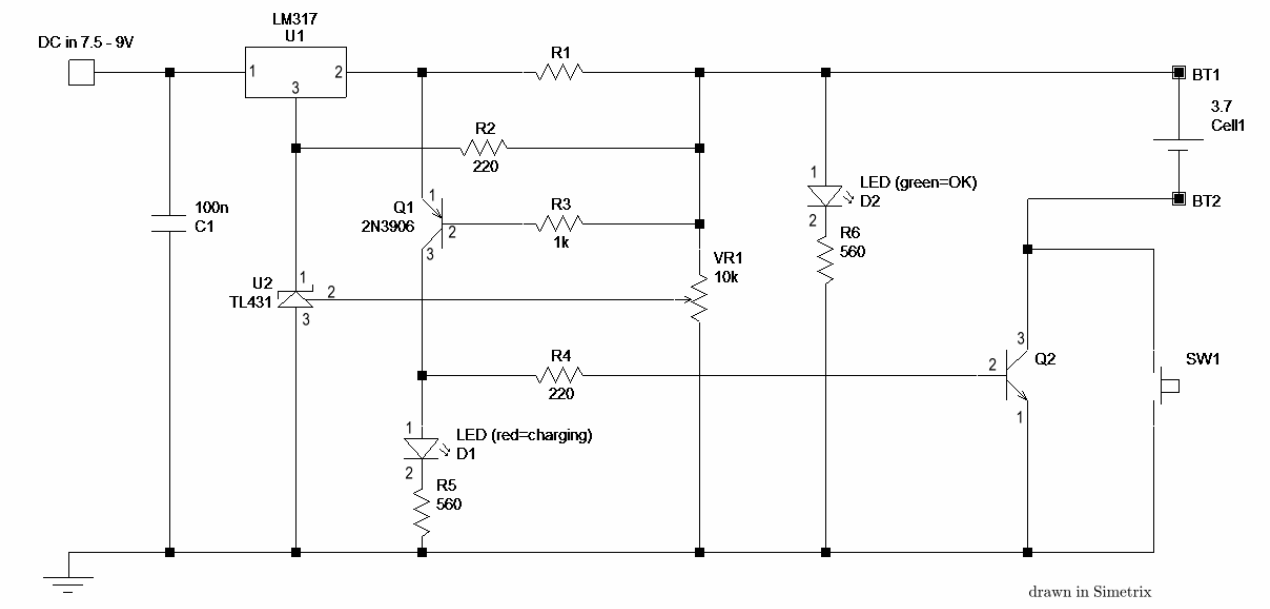
How many batteries can be charged at once?
This charger is intended to charge just one battery. With a higher voltage AC adapter ("wall-wart") and a higher maximum voltage setting in the circuit, you could charge two or more cells in series. However unless the cells are very well matched, you could find that one of them gets more voltage than the others, stressing it and making it likely to fail (see previous question about laptop batteries). Likewise, if you charge multiple cells in parallel, unless they are very well matched you could find that one gets more charging current than the others. What you do with your charger is your business, but I advise you to be careful and set conservative current and voltage limits if you decide to experiment with charging multiple batteries in series and/or parallel configurations.

How does it work?
The LM317 regulator is used primarily as a current limiter. During the constant-current phase of charging, the battery voltage rises steadily to maintain the current that is set by your choice of R1. Once the target voltage is hit, the TL431 conducts and stops the LM317 from increasing its output voltage any further. From now on, the current starts to decline from its preset value. Once the voltage drop across R1 is no longer sufficient to turn on Q1, Q1 and Q2 turn off, stopping charging altogether. To start charging a battery, it is necessary to press the button. The button 'jump-starts' the charging cycle by allowing current to flow. Since current is only allowed to flow if it is above a minimum value, the charging process would never start otherwise.

How do I use it?
Power-up the charger; the green LED comes on and it should stay on **all the time**. Connect a rechargeable lithium battery and press the button. Normally the red LED will come on indicating that charging is underway. When the red LED goes off, charging is complete. If the red LED will not stay on or quickly goes out, either the battery is already charged or the battery contacts are loose. If, when the button is pushed to start charging, the green LED dims or goes out, there is a fault (most likely the battery was connected backwards).

I hope you enjoy building and using this circuit. You are free to share it with others but please do so by sharing this entire document rather than any one part of it.

Schematic



Preparing for the Build

1. Determine how much current your AC adapter can supply while maintaining at least 7.5V at its output. There are large 'brick' resistors available if you want to test for yourself.

2. Choose a charging current that is less than or equal to the value you have from step 1. *Lower charging currents do mean longer charge times but the battery will end up getting a bit more charge.*

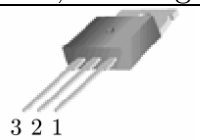
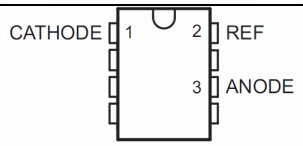
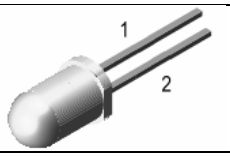
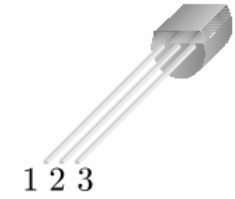
3. **Choose the current limiting resistor R1** to deliver your planned charging current (I_{chg}):

R1/Ω	I_{chg}/mA
3.6	320
3.2	360
2.4	460
2.2	500
2.0	540
1.8	630
1.6	720

Note: Resistor R1 must be a 2W rated resistor. These are several times larger than a 'normal' $\frac{1}{4}$-watt resistor.

4. **Choose transistor Q2**. If your charging current is up to 500mA, you can use a 2N2222 or an MPS651. If you will be charging at more than 500mA, you must use an MPS651.

5. Assemble the other parts listed here:

Part	Type or Value	Identification, Marking etc.
U1	LM317	
U2	TL431	
C1	100nF ceramic	104
SW1	switch	any momentary-ON pushbutton
D1	red LED	
D2	green LED	
Q1	2N3906	 Note: Q2 has same pin numbering scheme
VR1	any trimpot 5k-20k	multi-turn is nice but not essential.
R2, R4	220 Ω	red-red-brown OR red-red-black-black
R3	1kΩ	brown-black-red OR brown-black-black-brown
R5, R6	560 Ω	green-blue-brown OR green-blue-black-black

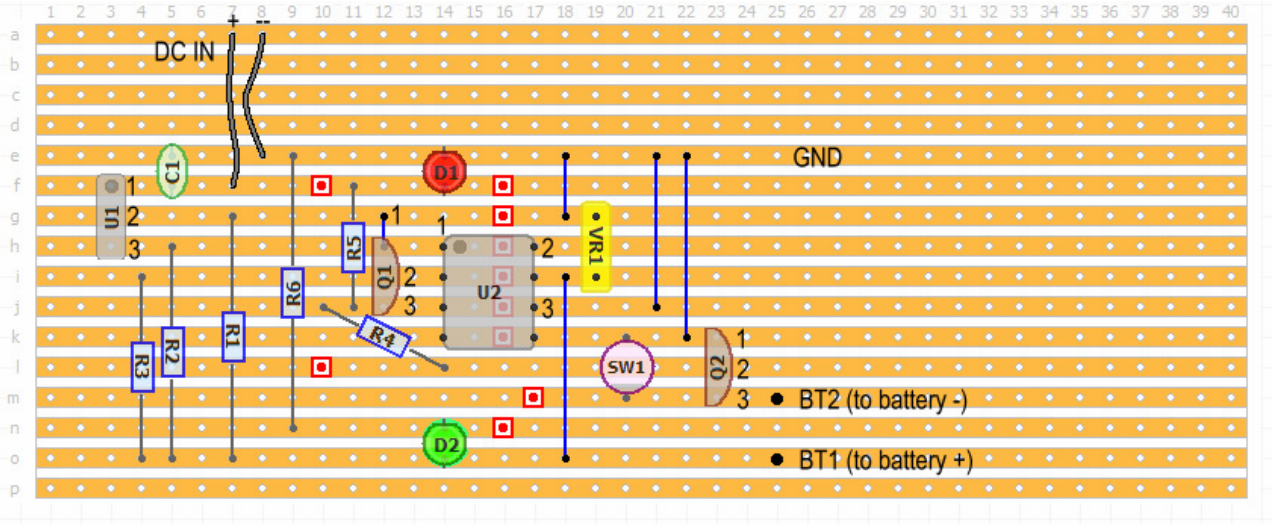
6. Decide how to attach the AC adapter to your circuit board. You will need either a matching connector (barrel jack) or, if you don't plan on using this particular AC adapter for anything else, a simple solution is to snip off its plug and solder the conductors directly to your circuit board. If you do this, a neat trick is to make a hole in the board near where you want to make the solder connections and feed the wire through the hole before soldering it in place. This relieves stress on the solder joints so the wires are less likely to break off.

7. Grab a heatsink for the LM317 regulator. If you are charging at a lower current, you can get away with a smaller heatsink. The bigger ones should be used by those building higher-current chargers. You will also need a nut and bolt. Assemble the 317 to the heatsink before soldering it into the circuit. Use enough thermal grease to make a thin film between the component and the heatsink, but not enough to squeeze out and form a thick bead around the part when you tighten it.

Build It !

1. Build the circuit however you like. Here is a suggested layout on stripboard. This is a view of the component side, meaning that the copper strips are actually on the back. It's as if the fibreglass material is transparent. A cut track is shown by a small square with a circle

inside. There are some cut tracks under U2. Also note that lead 1 of transistor Q1 hops over one track (it connects to track g, not track h). Blue lines are wire links.



2. Triple-check that all your connections are in place, and also that there are no unwanted ones. Scrutinize any cut tracks with a magnifying glass. I like to scrub the copper side with an old toothbrush to dislodge any copper or solder fragments.

3. Lastly, you need to equip your charger with battery terminals. You can make basic terminals using solid-core wire or break-away headers. Make sure to identify the positive and negative terminals somehow (coloured heat-shrink for example). Alternatively you can use the contact block from an old phone (or the phone carcass itself as a battery holder). Standard spade connectors are also a good sliding fit in the phone battery contacts. Basically there is a lot of room for improvisation here.

Setup and Test

You will need a lithium battery that is not fully charged (about 3.75V is ideal). Please follow this step-by-step setup process carefully. Record voltages to two decimal places.

1. First of all, make sure the potentiometer is roughly in the middle of its range, then apply power to the charger.

2. With no battery connected, adjust the potentiometer to give an output voltage of 4.50-4.60V measured between the **positive** battery terminal BT1 and GROUND.

3. Connect a partially charged cell (3.60V to 3.90V range) to the charger and press the button. The red LED should come on indicating charging is underway. Don't worry about the voltage being too high; because the cell is not fully charged it would take a while for the voltage to climb that high.

Measure and record the voltage between the battery terminals BT1 & BT2 ..... ☐

ⓘ If charging does not start when you press the button, or the green status LED dims or goes out, there is a fault (most likely you connected the battery backwards).
The green LED should always be on while the charger is powered.

4. While charging is underway (red and green LEDs both ON), measure and record the voltage between the **negative** battery terminal BT2 and GROUND ..... ☐

5. Remove the battery from the charger and adjust the output voltage (as in step 2) so that it is equal to your target voltage plus 0.7 times the voltage you just measured in step 4. For example, if I measured 0.26V in step 4 and I want to charge my battery to 4.15V, I set my output voltage to $4.15 + 0.7 \times 0.26 = 4.33$V. If I want to charge my battery to 4.10V, I set my output voltage to $4.10 + 0.7 \times 0.26 = 4.28$V. Remember, this is the voltage between the positive battery terminal (BT1) and GROUND.

6. Do a test run. Set the target voltage about 0.1 to 0.2V above the voltage you recorded in step 3 − that way you won't have to wait too long for the charge to complete.

7. When you've confirmed that the charger cuts off at, or very close to, the target voltage, you can set the target voltage to any value you like up to a sensible maximum of 4.2V. I generally prefer to charge lithiums to a lower voltage (from 4.0 to 4.1 V) as this helps prolong the life of the battery. However since this charger does a relatively short saturation charge (the part after the voltage limit is reached), it's fine to go up to 4.2V.

Notes

1. It is recommended not to leave lithium batteries charging unsupervised, and/or surrounded by flammable materials. Also, don't leave the charger switched on for long periods of time when not in use. Do not charge lithium batteries over 4.2V.

2. The first few times you charge a battery 'for real', check that charge termination occurs at or very close to your target voltage. When you have verified correct operation, you can apply a drop of hot glue or epoxy to the edge of the trimpot to make sure it stays put.

3. When using lithium batteries, don't allow them to discharge below 3.4V. Don't charge batteries which have been allowed to discharge below 3V, and/or subjected to heavy shock or impact (e.g model aircraft crashed hard). They may be unsafe! If in doubt, ♲ it.

4. Lithium-ion batteries have no memory effect, so partial charges are fine. Also, this charger doesn't mind if you connect and disconnect batteries while it is switched on.

5. If you charge a battery using long wires connected to the charger, it will charge up to a lower voltage than you expect. This is because some of the voltage is dropped in the connecting wires. Under typical conditions and with wires of about 50cm length, the difference might be around 0.1V. This doesn't mean your battery isn't charged, it just isn't quite as charged. Something to be aware of if you plan to charge batteries that are (semi-) permanently installed in devices. Investigate and compensate as necessary.