Li-ion batteries: basics and usage tips

(2nd classified essay)

"Don't let that phone charging overnight, it can explode!" Is this something that only my mother says? Or is this a sentence that you also eared many times or even that you said yourselves? Also, have you ever been said to plug in your smartphone only when the battery is completely dead? We charge our smartphones' battery once a day (on average) and we complain about its "fast discharge" once… an hour?!

So let's talk about this small but important "thing" that is in everyone's phone. First, there exist many types of batteries, but currently commercial smartphones (and laptops, tablets) mainly contain Lithium-ion (Li-ion) batteries. Li is the third element of the periodic table, first column, top left: "alkali metal" is how the elements in that column are called. - This is a bit out of topic but 2019 marks 150 years from the born of the periodic table, so let's celebrate this neat arrangement of messy cornerstones! – And if you want to know more about Lithium, there is a brilliant TED Talk that I strongly invite you to watch.[1]

The idea behind a battery is to use the energy released by chemical reactions to produce electricity. In Li-ion batteries, the chemistry is all about the movement of Li ions, which are positively charged and very tiny (its diameter is about a million times smaller than the one of a human hair). Li ions move between two electrodes, the cathode and the anode, passing through the electrolyte. Cathode, anode and electrolyte constitute an electrochemical cell, and one or more cells form a battery. There are other components, but let's keep it simple. As Li ions move, electrons move in the same direction in a connected external circuit.

If you are confused, a classic science-demo helps to "visualize" a battery interior without opening your phone: the lemon battery. I will tell you how to make these batteries in a future post, for now I want you to identify the components: i) the lemon juice is our electrolyte; ii) two pieces of different metals partially inserted into the lemon are our electrodes, connected through wires. Metal ions are generated at the interface between anode and electrolyte, enabling the flow of electrons in the wire.

Now that you have located the various pieces, let's go back to Li ions. The main difference between a lemon and a Li-ion battery (OK, it is plenty of differences!) is that the second is rechargeable, meaning that Li ions move in both directions across the electrolyte and the battery operation is reversible. When the battery is charging, Li ions move from the positive to the negative electrode (see the figure below), where they are stored. The negative electrode is typically formed by graphite (yes, like a pencil… almost!): its structure can be seen as parallel sheets of connected hexagons made of carbon atoms, and Lithium is stored in between these sheets. When you use your phone, the battery discharges: Li ions are released from the negative to the positive electrode. We commonly say that the negative electrode is the anode and the positive electrode is the cathode, although this is formally true only during discharge. The cathode is generally a beautiful but complicated structure composed of lithium, another metal and oxygen, sometimes also phosphorous. Remember that when Li ions move electrons move as well.

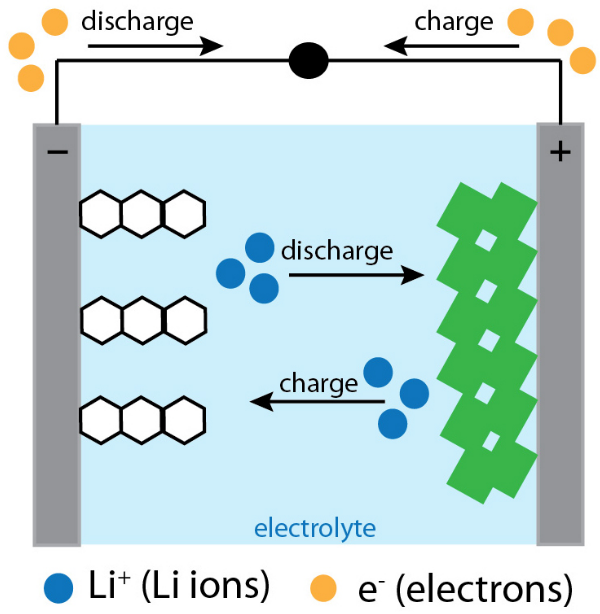

Figure 1. Super simplified 2D scheme of a Li-ion battery.

Now, we should first reassure my mother: no the phone won't explode if plugged in overnight. Batteries are equipped with chips that will stop the charging process once the battery reaches 100% of its capacity (storable energy). However, there is some truth beyond my mother's fear. Electrochemical reactions and mass-transport phenomena are simultaneously occurring in a battery: overall performance depends on operating conditions and storage temperature, parameters that we can somewhat control.

Analyzing batteries' performance means investigating mechanisms of batteries' ageing. Ageing with time and use mainly cause (and are caused by) changes at the anode/electrolyte interface and in the active material of both electrodes.[2] Capacity and power fade are enhanced by storing batteries at high state of charge (SOC) and high temperatures. A solid interphase self-forms during first charge/discharge cycles and somehow protects the anode, but its growth and structural changes during successive cycles increase the impedance ("resistance") of the electrode, leading to power fade. High temperatures (particularly >60 °C) can break this interphase and accelerate the movements of Li ions, increasing the occurring of undesired (and sometimes unpredictable) side-reactions. High temperatures also favor self-discharge of the battery, enhancing modifications in electrode materials.[3] Low temperatures instead slow down the movement of Li ions and favors the plating (deposition) of Li metal, changing the overall composition and decreasing the amount of moving Li ions, hence worsening the performance.[2]

Low temperatures (particularly <-10 °C) are more detrimental during charge than discharge. Finally, both low and high SOC deepens structural changes and undesired reactions at the cathode. The take-home message here is that both high and low states of charge and high and low temperatures have negative impact on Li-ion batteries performances. In practice, keeping smartphones and laptops at 10-25 °C and

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avoiding full charge/discharge retard battery aging. Essentially, better to charge the battery more frequently but for shorter time: plug it in when the charge is about 25-30% and unplug when it reaches 80%. This is typically implemented in batteries for electric and hybrid electric vehicles, which never reach complete charge or discharge.

The good news is that it is very likely that you will buy a new phone or laptop before the batteries of your “old” (but Gold) devices will significantly loose capacity!

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Bibliography

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