Lithium Ion Batteries

What are lithium ion batteries and how do they work?

Tyler Bartholome, Kie Hankins, Nick Keller
CHEM 362, Section 500

Abstract

Lithium ion batteries are batteries that function based on the transfer of lithium ions between a cathode and an anode.

Lithium ion batteries have higher specific energies than batteries made from other materials such as zinc and lead due to the relatively light weight and low density of lithium. Lithium batteries are also more stable over charge/recharge cycles due to the small radii of lithium ions, which causes fewer disruptions of the electrode structure during ion transfer. Lithium ion batteries commonly use graphite and cobalt oxide as additional electrode materials.

Lithium ion batteries work by using the transfer of lithium ions and electrons from the anode to the cathode. At the anode, neutral lithium is oxidized and converted to Li^+. These Li^+ ions then migrate to the cathode, where they are incorporated into $LiCoO_2$. This results in the reduction of Co(IV) to Co(III) when the electrons from the anode reaction are received at the cathode. Because lithium is involved in the reactions at both electrodes, the battery can be recharged by running the reactions in reverse.

What they are

"A battery is a device that is able to store electrical energy in the form of chemical energy, and convert that energy into electricity" [2]

There are two main categories of lithium ion batteries: primary (single-use) and secondary (rechargeable).

Primary batteries most commonly use a reaction between Li and MnO_2 to produce electricity while secondary batteries use a reaction in which lithium from a lithium/graphite anode is incorporated into $LiCoO_2$ at the cathode.

Applications

Used in portable devices such as cell phones, wrist watches and laptop computers due to their relative light weight

Another benefit of their light weight is that they can be used in aerospace technologies such as satellites and space probes.

Higher energy density makes them suitable for use in all-electric vehicles as well as in power tools and implanted medical devices.

Lithium ion batteries are also used for solar and wind power storage.
In all of these cases, secondary batteries are generally used.

References

(1) Shriver, D.; Weller, M.; Overton, T.; Rourke, J.; Armstrong, F. *Inorganic Chemistry,* 6th ed.; W. H. Freeman and Company: New York, 2014.
(2) Massachusetts Institute of Technology. Ask an Engineer: How Does a Battery Work? http://engineering.mit.edu/ask/how-does-battery-work (accessed Mar 30, 2017).
(3) University of Minnesota. Lithium-Ion Battery with Higher Charge Capacity. http://license.umn.edu/technologies/20140204_lithium-ion-battery-with-higher-charge-capacity (accessed Mar 30, 2017).
(4) Lowe, M.; Tokuoka, S.; Trigg, T.; Gereffi, G. *Lithium-ion Batteries for Electric Vehicles: The U.S. Value Chain.* Duke University, 2010.
(5) Valle, Bruno Do, Christian T. Wentz, and Rahul Sarpeshkar. "An Ultra-compact and Efficient Li-ion Battery Charger Circuit for Biomedical Applications." Proceedings of 2010 IEEE International Symposium on Circuits and Systems (ISCAS). 1224–1227. © Copyright 2010 IEEE
(6) *Rechargeable Li-ion battery systems: Light energy storage for space applications.* Saft Specialty Battery Group: Cockeysville, MD, 2006.
(7) Physics Today. Batteries and electrochemical capacitors. http://physicstoday.scitation.org/doi/10.1063/1.3047681 (accessed Mar 30, 2017).
(8) Islam, M. S.; Fisher, C. A. J. Lithium and sodium battery cathode materials: computational insights into voltage, diffusion and nanostructural properties. *Chem. Soc. Rev.* [Online] **2013**, *43,* 185-204.

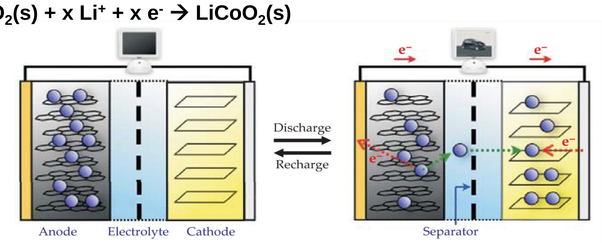
How they work

During discharge, lithium is oxidized from Li to Li^+ (0 to +1 oxidation state) in the lithium-graphite anode through the following reaction:

$C_6Li \rightarrow 6\ C(graphite) + Li^+ + e^-$

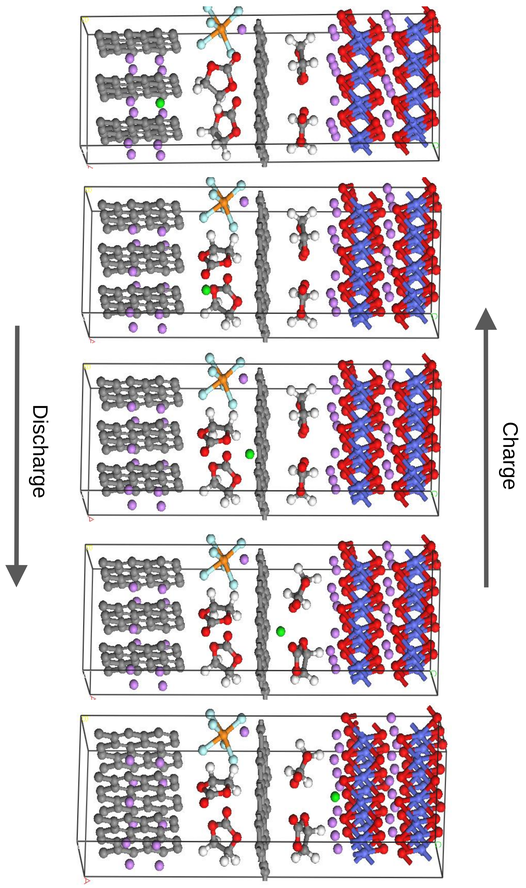
These lithium ions migrate through the electrolyte medium to the cathode, where they are incorporated into lithium cobalt oxide through the following reaction, which reduces cobalt from a +4 to a +3 oxidation state :

$Li_{1-x}CoO_2(s) + x\ Li^+ + x\ e^- \rightarrow LiCoO_2(s)$



These reactions can be run in reverse to recharge the cell. In this case the lithium ions leave the lithium cobalt oxide cathode and migrate back to the anode, where they are reduced back to neutral lithium and reincorporated into the graphite network.

Cycle



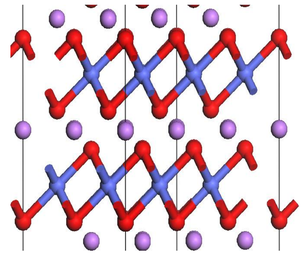
Cathode

The cathode is most commonly a lithiated metal oxide. There are main 3 types:

Layered oxide like Li_xCoO_2

Polyanion materials such as $LiFePO_4$ and Li2FeSiO4

Spinel oxides like $LiMn_2O_4$



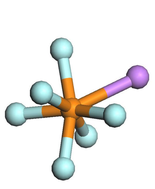
Li_2CoO_2
(HCP structure)

Electrolyte

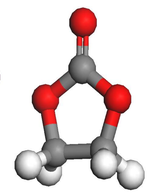
There are many different kinds of materials that are used as electrolytes. All of them are based on a lithium-containing material that allows for the easy diffusion of lithium.

Liquid: Most commonly used today. Often use $LiPF_6$ or similar lithium salt and Ethylene Carbonate as a solvent.

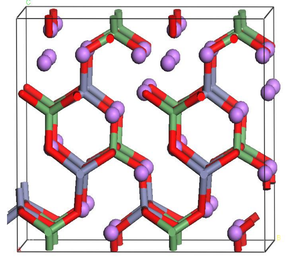
Solid State and polymer: Are being researched, but are rarely used due to the low diffusivity of lithium.



$LiPF_6$



Ethylene Carbonate

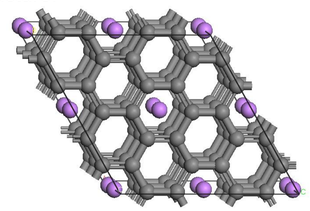


Solid Electrolyte:
$Li_{10}Zn_3(GeO_4)_4$

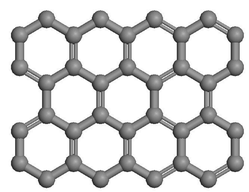
Anode

One of the most common anode materials used today is lithiated graphite, Li_xC_6, which is composed of graphene sheets intercalated with lithium.

New materials such as those based on Silicon and other elemental blends are being researched. Lithiated graphite has a unit cell with a HCP structure.



Lithiated Graphite



Graphene