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# Lithium ion batteries

A Scientific Essay

**By**

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Since the middle of the last century, the growing global demand for energy, the concern about the depletion of traditional energy sources, such as oil, coal and natural gas, and the environmental impacts resulting from their use, have led to improved alternative sources of energy which are renewable and non-harmful to the environment such as wind and solar energy (1). The low costs of production and maintenance, simple operation, high efficiency and long lifetime are the most unique requirements for storage systems used with renewable energy applications (2). To fulfil these requirements, work began on the development of different types of batteries such as lead-acid and lithium ion batteries (3).

Rydh & Sanden stated that the energy required for production and transport of lithium ion batteries is less than that for lead-acid batteries (4). The reason is that the specific energy (the energy stored per unit weight) of lead-acid batteries is small relative to that for lithium ion batteries, because the low atomic weight and higher voltage of lithium leads to higher specific energy. Moreover, lifetimes of lead-acid batteries are limited and less than that for lithium ion batteries, which means that lead-acid batteries should be replaced more often, resulting in raising the cost of production and transportation. In addition, the lithium ion batteries has less loss of energy, i.e. the highest energy efficiency (charge-discharge) compared with all other types of batteries (3). A low efficiency will increase the cost because low battery efficiency results in a larger PV array and charger (4).

The low cost and the availability of lead-acid batteries around the world make them the most common batteries in the renewable energy applications (3), however, the low specific energy and lifetime has lead researchers to look for alternative batteries that can meet these requirements. Lithium ion batteries are considered as one of the most promising electrochemical storage systems. Due to high specific capacity and long lifetime (for example $LiFePO_4$ have a theoretical capacity of 170 $mAh.g^{-1}$) (5-8), lithium ion batteries can be coupled to renewable energy sources like solar and wind (9,10) and to power the next generation of portable electronic devices including laptops and mobile phones, as well as power systems for electric vehicle applications (11).

Lithium metal, due to its highest specific capacity, had been used in the earliest compositions of rechargeable lithium cells as the negative electrode materials with chalcogenides as positives (6). Irregular precipitation of metallic lithium on the negative electrode during cycling led to generation of lithium dendrites. Dendrite growth on the lithium surface could penetrate the separator and resulting in short circuiting of the cell (12). In order to solve the safety concern arises from lithium dendrite formation, research was shifted towards replacing lithium metal electrode by an insertion material that can provide a host for lithium ions. This can be represented in Figure 1, which shows clearly the dendrite formation at the surface of lithium metal using the metallic lithium

electrode (a), and the effect of replacing lithium metal by an insertion material to eliminate the dendrite growth (b).

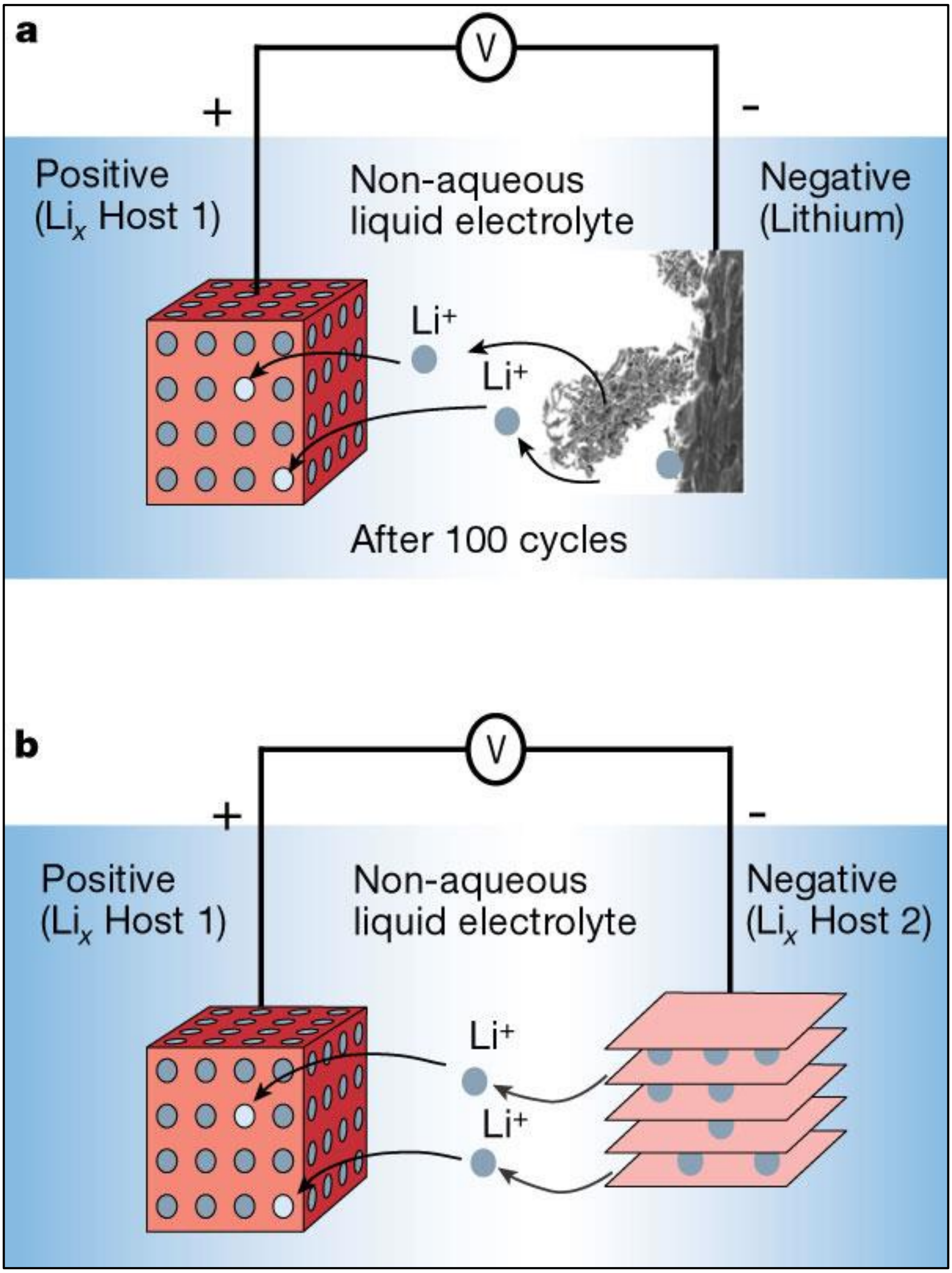


Figure 1 Schematic representation of (a) Rechargeable Li metal battery, and (b) Rechargeable Li ion battery, showing the occurrence and the avoidance of dendritic of lithium plating in the former.

Lithium cobalt oxide ($LiCoO_2$) as a positive electrode with carbon as a negative electrode is the first commercial rechargeable lithium ion battery which was

introduced by Sony in 1991 (13). The expression lithium-ion battery refers to a battery in which the mobile lithium ions exchange between two host lattices in the positive and negative electrodes.

$LiCoO_2$ was used as the positive electrode in the most common rechargeable lithium ion batteries that was widely used in the market. The toxicity and high cost of elemental cobalt led to a search for other positive insertion compounds such as lithium iron phosphate ($LiFePO_4$), which considered to be the most attractive candidate as a cathode for rechargeable lithium ion batteries, due to its low cost, nontoxicity and environmentally acceptance (14).

Rechargeable lithium ion batteries consists of a positive electrode formed by a lithium transition-metal oxide or phosphate, combined with carbon as a negative electrode material, separated by an electrolyte solution consisting of a lithium salt in a mixed organic solvents (15). A convenient electrolyte that is used in lithium ion batteries must have high chemical stability, suitable ionic conductivity, low cost and satisfying safety requierments (15). An electrolyte consists of an inorganic lithium salt dissolved in organic solvents which enable lithium ion transfer between positive and negative electrodes (9).

Common Lithium salts used frequently in electrolytes of lithium ion batteries should be inert towards the cell components with a high solubility in the organic solvents, such as lithium hexafluorophosphate ($LiPF_6$) (16, 17), lithium perchlorate ($LiClO_4$) (18), lithium tetrafluoroborate ($LiBF_4$) (19, 20), lithium hexafluoroarsenate ($LiAsF_6$) (21, 22), and Lithium bis(trifluoromethane sulfonyl) imide (LiTFSI) (23). Combining of two or more organic solvents is often used to improve the properties of the electrolyte. Main organic solvents used in lithium ion batteries are ethylene carbonate (EC), propylene carbonate (PC), diethyl carbonate (DEC), dimethyl carbonate (DMC), and 1,2-dimethoxyethane (DME) (24).

Lithium ion cells operate on the basis of intercalation reaction which involves the extraction/insertion of lithium ions between the two electrodes (15, 25). The chemical reactions that take place in the electrodes in lithium ion cell, using for example $LiCoO_2$ as a positive electrode and carbon as a negative electrode, can be simply demonstrated by the following equations:

Charge process

Positive electrode $LiCoO_2 \rightarrow CoO_2 + Li^+ + e^-$ (1)

Negative electrode $6C + Li+ + e^- \rightarrow LiC_6$ (2)

Discharge process

Positive electrode $CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$ (3)

Negative electrode $LiC_6 \rightarrow 6C + Li^+ + e^-$ (4)

When the cell charge (equations 1 and 2), the lithium ions are extracted from the positive electrode and migrate through the electrolyte to intercalate in the carbon negative electrode. During the discharge (equations 3 and 4), the lithium ions move back to the positive electrode from the negative electrode (15, 27). This reaction causes a flow of electrons used to power an electric device (Figure 2).

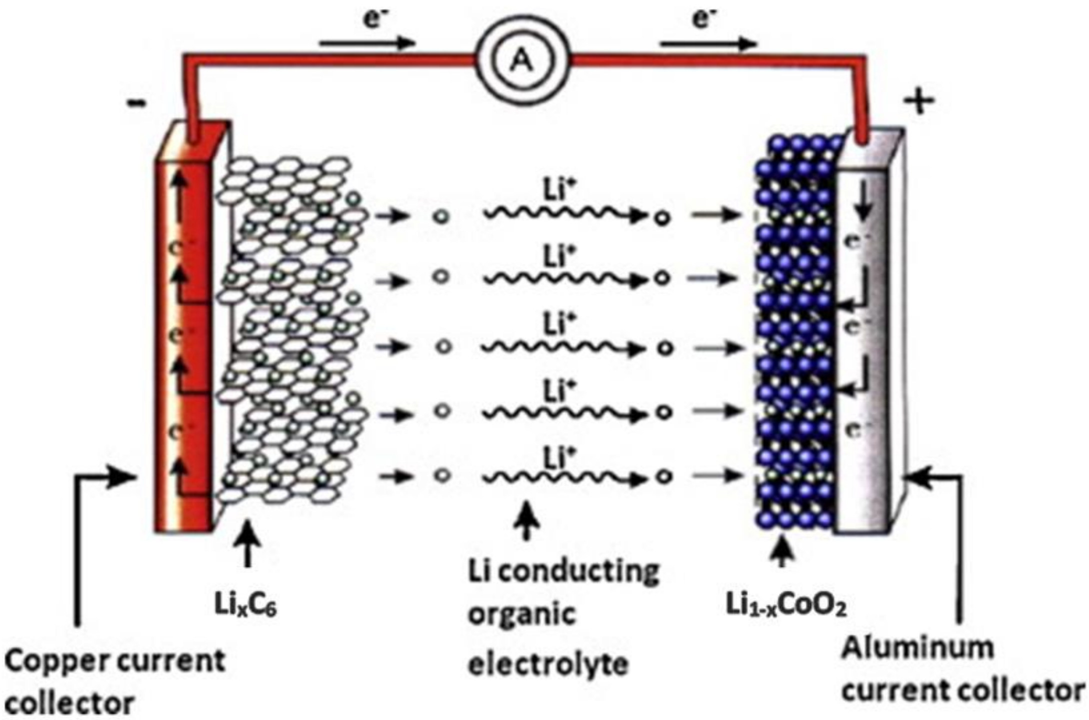


Figure 2 Scheme of a common lithium ion battery.

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