

How does a lithium ion battery work chemistry

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Lithium-ion batteries power the lives of millions of people each day. From laptops and cell phones to hybrids and electric cars, this technology is growing in popularity due to its light weight, high energy density, and ability to recharge.

While the battery is discharging and providing an electric current, the anode releases lithium ions to the cathode, generating a flow of electrons from one side to the other. When plugging in the device, the opposite happens: Lithium ions are released by the cathode and received by the anode.

The two most common concepts associated with batteries are energy density and power density. Energy density is measured in watt-hours per kilogram (Wh/kg) and is the amount of energy the battery can store with respect to its mass. Power density is measured in watts per kilogram (W/kg) and is the amount of power that can be generated by the battery with respect to its mass. To draw a clearer picture, think of draining a pool. Energy density is similar to the size of the pool, while power density is comparable to draining the pool as quickly as possible.

The Department of Energy's Vehicle Technologies Office (VTO) works on increasing the energy density of batteries, while reducing the cost, and maintaining an acceptable power density. For more information on VTO's battery-related projects, please visit the Vehicle Technologies Office website.

Pioneering work of the lithium battery began in 1912 under G.N. Lewis, but it was not until the early 1970s that the first non-rechargeable lithium batteries became commercially available. Attempts to develop rechargeable lithium batteries followed in the 1980s but failed because of instabilities in the metallic lithium used as anode material. (The metal-lithium battery uses lithium as anode; Li-ion uses graphite as anode and active materials in the cathode.)

The inherent instability of lithium metal, especially during charging, shifted research to a non-metallic solution using lithium ions. In 1991, Sony commercialized the first Li ion, and today this chemistry has become the most promising and fastest growing battery on the market. Although lower in specific energy than lithium-metal, Li ion is safe, provided the voltage and currents limits are being respected. (See BU-304a: Safety Concerns with Li-ion)

The key to the superior specific energy is the high cell voltage of 3.60V. Improvements in the active materials and electrolytes have the potential to further boost the energy density. Load characteristics are good and the flat discharge curve offers effective utilization of the stored energy in a desirable and flat voltage spectrum of 3.70-2.80V/cell.

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Li-ion is a low-maintenance battery, an advantage that most other chemistries cannot claim. The battery has no memory and does not need exercising (deliberate full discharge) to keep it in good shape. Self-discharge is less than half that of nickel-based systems and this helps the fuel gauge applications. The nominal cell voltage of 3.60V can directly power mobile phones, tablets and digital cameras, offering simplifications and cost reductions over multi-cell designs. The drawbacks are the need for protection circuits to prevent abuse, as well as high price.

Lithium-ion uses a cathode (positive electrode), an anode (negative electrode) and electrolyte as conductor. (The anode of a discharging battery is negative and the cathode positive (see BU-104b: Battery Building Blocks). The cathode is metal oxide and the anode consists of porous carbon. During discharge, the ions flow from the anode to the cathode through the electrolyte and separator; charge reverses the direction and the ions flow from the cathode to the anode. Figure 1 illustrates the process.

Li ion batteries come in many varieties but all have one thing in common - the "lithium-ion" catchword. Although strikingly similar at first glance, these batteries vary in performance and the choice of active materials gives them unique personalities. (See BU-205: Types of Li-ion-ion)

Sony's original lithium-ion battery used coke as the anode (coal product). Since 1997, most Li ion manufacturers, including Sony, shifted to graphite to attain a flatter discharge curve. Graphite is a form of carbon that has long-term cycle stability and is used in lead pencils. It is the most common carbon material, followed by hard and soft carbons. Nanotube carbons have not yet found commercial use in Li-ion as they tend to entangle and affect performance. A future material that promises to enhance the performance of Li-ion is graphene.

Several additives have been tried, including silicon-based alloys, to enhance the performance of the graphite anode. It takes six carbon (graphite) atoms to bind to a single lithium ion; a single silicon atom can bind to four lithium ions. This means that the silicon anode could theoretically store over 10 times the energy of graphite, but expansion of the anode during charge is a problem. Pure silicone anodes are therefore not practical and only 3-5 percent of silicon is typically added to the anode of a silicon-based to achieve good cycle life.

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