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A Short Review of Lithium-ion Battery Technology

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ABSTRACT

Lithium batteries are characterized by high specific energy, high efficiency and long life. These unique properties have made lithium batteries the power sources of choice for the consumer electronics market with a production of the order of billions of units per year. These batteries are also expected to find a prominent role as ideal electrochemical storage systems in renewable energy plants, as well as power systems for sustainable vehicles, such as hybrid and electric vehicles. However, scaling up the lithium battery technology for these applications is still problematic since issues such as safety, costs, wide operational temperature and materials availability, are still to be resolved. This review focuses first on the present status of lithium battery technology, then on its near future development and finally it examines important new directions aimed at achieving quantum jumps in energy and power content.

Keywords: Lithium-Ion Battery, Power Source, Storage Cell, Recharge Cells, Li-ion Technology

I. INTRODUCTION

The present energy economy based on fossil fuels is at a serious risk due to a series of factors, including the continuous increase in the demand for oil, the depletion of non-renewable resources and the dependency on politically unstable oil producing countries. Another worrying aspect of the present fossil fuel energy economy is associated with CO2 emissions, which have increased at a constant rate, with a dramatic jump in the last 30 years, the CO2level has almost doubled passing from 1970 to 2005, this resulting in a rise in global temperature with associated series of dramatic climate changes. The urgency for energy renewal requires the use of clean energy sources at a much higher level than that presently in force. The CO2 issue, and the consequent air pollution in large urban areas, may be only solved by replacing internal combustion engine (ICE) cars with ideally, zero emission vehicles, i.e. electric vehicles (EVs) or, at least, by controlled emission vehicles, i.e. full hybrid electric vehicles (HEVs) and/or plug-in electric vehicles (PHEVs). Electrochemical systems, such as batteries and super capacitors, that can efficiently store and deliver energy on demand in stand-alone power plants, as well as provide power quality and load levelling of the electrical grid in integrated systems, are playing a crucial role in this field. Indeed, the advantage of the use of electrochemical storage systems has been demonstrated for both wind and photovoltaic REPs [1]. The efficacy of batteries in REPs is directly related to their content in energy efficiency and lifetime. Indeed, in virtue of their high value of energy efficiency, lithium batteries are expected to provide an energy return factor higher than that assured by conventional batteries, e.g. lead-acid batteries [2]. In addition to REPs, lithium ion batteries are also seen as the power sources of choice for sustainable transport because they are considered the best options which can effectively guarantee the progressive diffusion of HEVs, PHEVs, and BEVs at high levels [3]. In HEVs the synergic combination of ICE with an electrochemical battery provides high fuel utilization with proven benefits for fuel economy and therefore, for pollution emission control, as well as favouring driving performances which are similar if not superior to those of pure gasoline cars. Indeed, the production of battery-powered HEVs has very rapidly passed from demonstration prototypes to very successful commercial products, see Fig. 1. However, problems of various natures still prevent the largescale diffusions of lithium ion batteries for REP and EV applications. Several countries, including Japan, United States and Europe, are allocating large investments to support R&D programs aimed to solve these problems and thus promote the development of advanced, efficient lithium batteries [4].

II. CELLS AND BATTERY

An electrochemical cell is a device that converts chemical energy to electrical energy. A battery is a collection of one or more such cells. In this sense, we can say the simplest battery is a unitary cell. In 1786, Luigi Galvani, observed that when he touched a dead frog's leg is touched with two different metals, the muscles of the legs contracted. In 1800, Alessandro Volta analyzed that phenomenon and developed the first prototype of a battery using copper and zinc electrodes. Batteries underwent subsequent development over the next two centuries and are of two types, the primary cell type (not rechargeable) and the secondary cell type (rechargeable). The Lithium-ion battery is a modern development from the Lithium battery and is a rechargeable one contrary to Lithium batteries.

III.CHRONICLE OF DEVELOPMENT

The chronicle of development of these batteries is tabulated herein:

Table 1 – Chronicle of Development of Li-Ion Batteries

YEAR	NAME OF SCIENTISTS	CONTRIBUTION
1973	Adam Heller	Proposed the non rechargeable Lithium thionyl chloride battery with high energy density but extreme operating temperatures.
1977	Samar Basu	Demonstrated the electrochemical intercalation phenomenon of Lithium in Graphite at University of Pennsylvania.
1980	John Goodenough & Koichi Mizushima	Demonstrated a rechargeable Li-ion battery with Lithium Cobalt Oxide ($LiCoO_2$).
1980	Rachid Yazami	Demonstrated the process of reversible electrochemical intercalation of lithium in graphite.
1991	Sony	Developed the first commercial Li-ion batteries.
2002	Yet Min Chiang et al.	Demonstrated a marked improvement in performance of a battery doped with aluminium, niobium and zirconium.

IV.MATERIALS AND CONSTRUCTION

It has four fundamental components: a positive electrode, a negative electrode, an electrolyte and a separator. The most commonly used negative electrode is graphite. The positive electrode is generally made of lithium cobalt oxide, lithium iron phosphate or lithium manganese oxide. The electrolyte is typically a mixture of lithium salts in ethylene carbonate. Commonly used lithium salts include : lithium hexafluorophosphate (LiPF6), lithium hexafluoroarsenate monohydrate (LiAsF6.H20), lithium perchlorate (LiClO4) etc. The separator is a fine porous polymer film such as polyethylene, polypropylene.

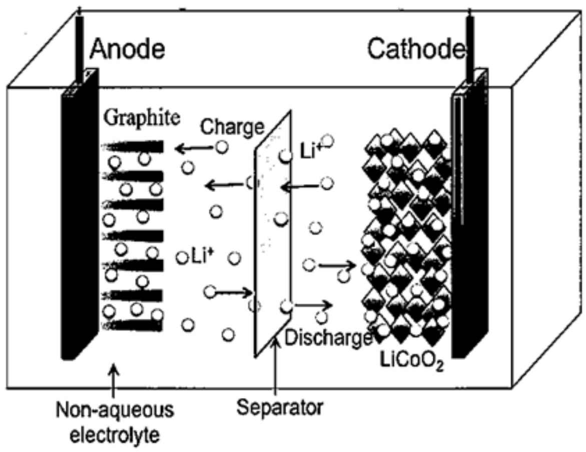

Figure 1 – Cell Construction

According to Scientist David Andrea, these batteries are of four types:

1. Small cylindrical (solid body without protruding terminals, such as those used in laptop batteries).
2. Large cylindrical (solid body with large threaded terminals).
3. Pouch (soft, flat body, such as those used in cell phones; also referred to as li-ion polymer or lithium polymer batteries).
4. Prismatic (semi-hard plastic case with large threaded terminals, such as vehicles' traction packs).

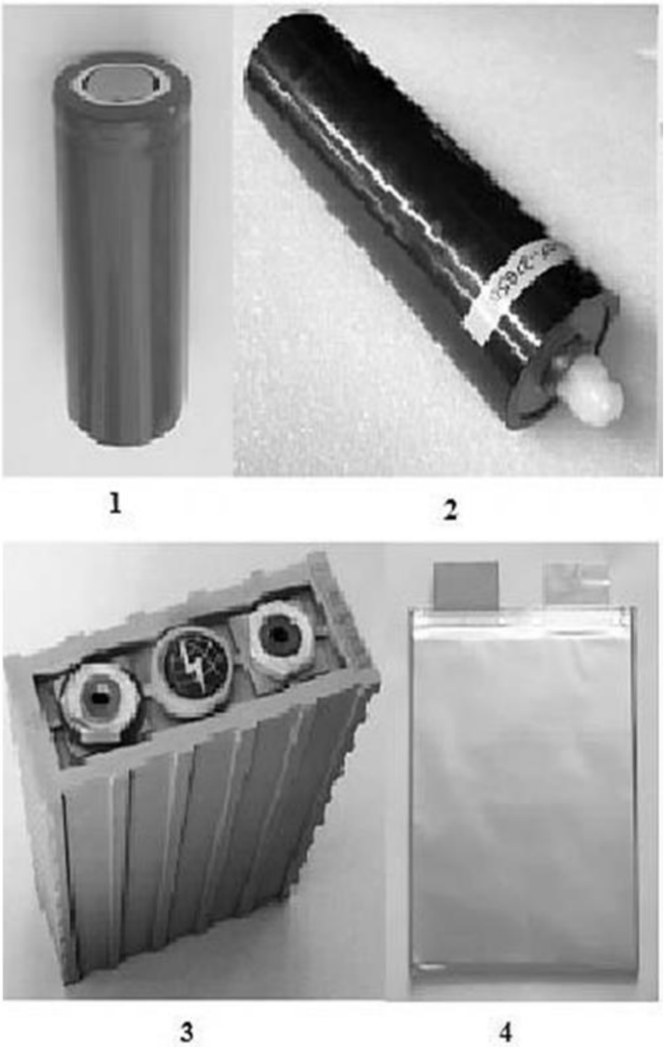

Figure 2 – Types of Lithium-Ion Batteries

V. CHEMISTRY OF LI-ION CELLS

Most commonly, LiCoO2 is used in the positive electrode (cathode) and graphite (C6) is used in the negative electrode (anode). Both electrodes allow lithium ions to move in and out of their structures in intercalation or deintercalation processes. During discharge, the positive lithium ions move from the negative electrode (usually graphite) to the positive electrode (forming a lithium compound) through the electrolyte while the electrons flow through the external circuit in the same direction.

The positive (cathode) electrode half-reaction:

$CoO_2 + Li^+ + e^- \rightleftarrows LiCoO_2$

The negative (anode) electrode half-reaction:

$LiC_6 \rightleftarrows C_6 + Li^+ + e^-$

The overall reaction thus can be given as:

$LiC_6 + CoO_2 \rightleftarrows C_6 + LiCoO_2$

VI. CHARGING AND DISCHARGING CHARACTERISTICS

The cathode (+) marking and anode (-) marking are done with regards to the discharging process. It is to be noted that the marked cathode (+) terminal is the positive terminal during discharging only and becomes the negative terminal during charging. Similarly, the marked anode (-) terminal is the negative terminal during discharging only and becomes the positive terminal during charging.

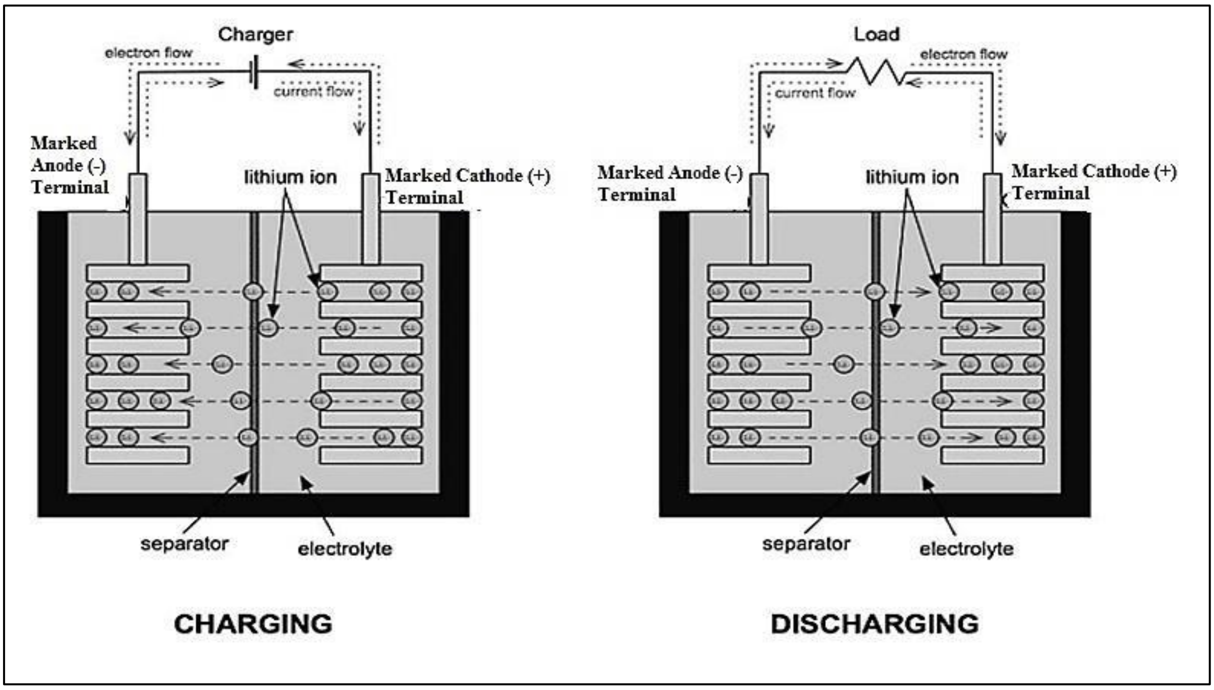

Figure 3 – Charging and Discharging Processes

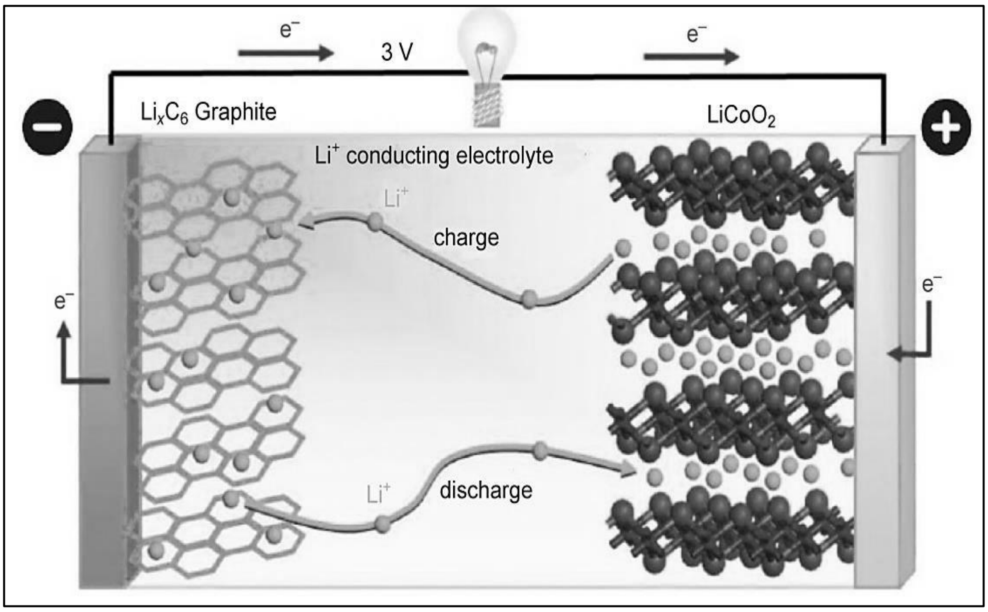

Figure 4 – Flow of Electrons During Discharging

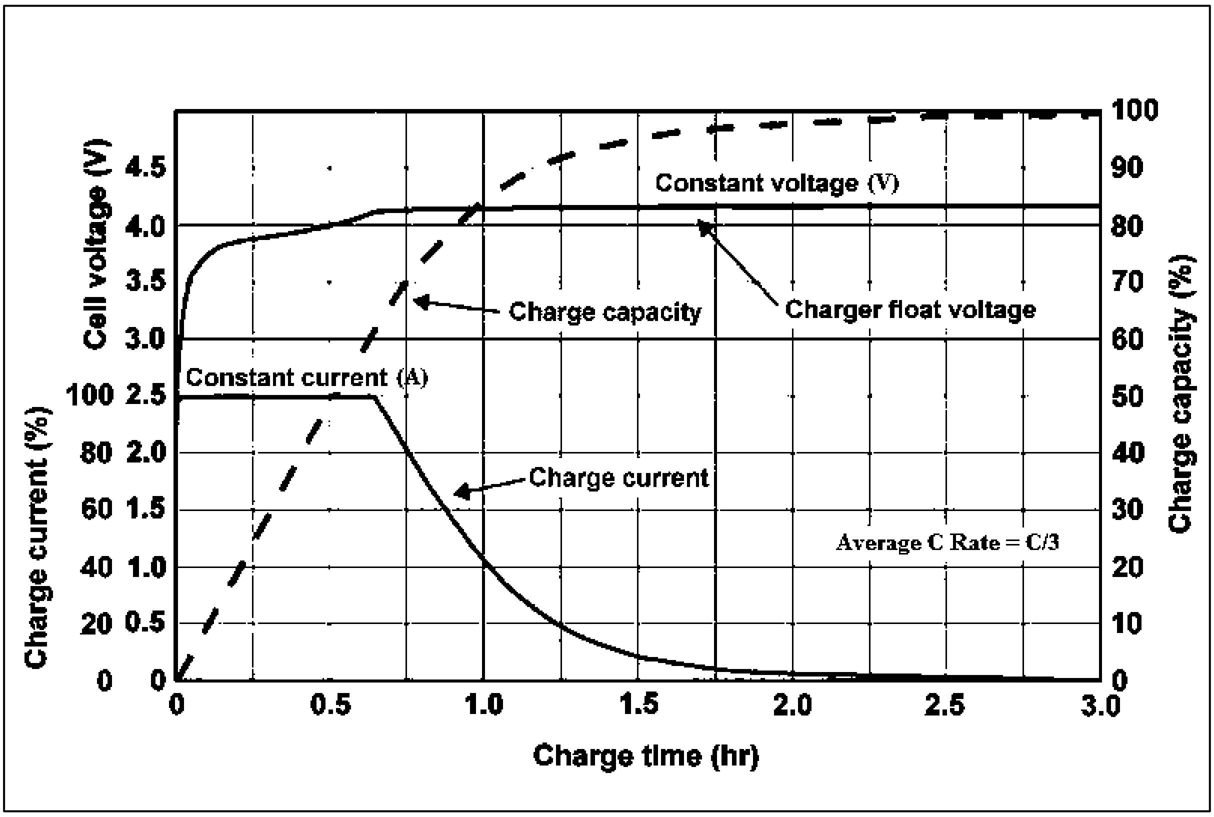

Figure 5 – Charging Characteristics for C – Rate of C/3

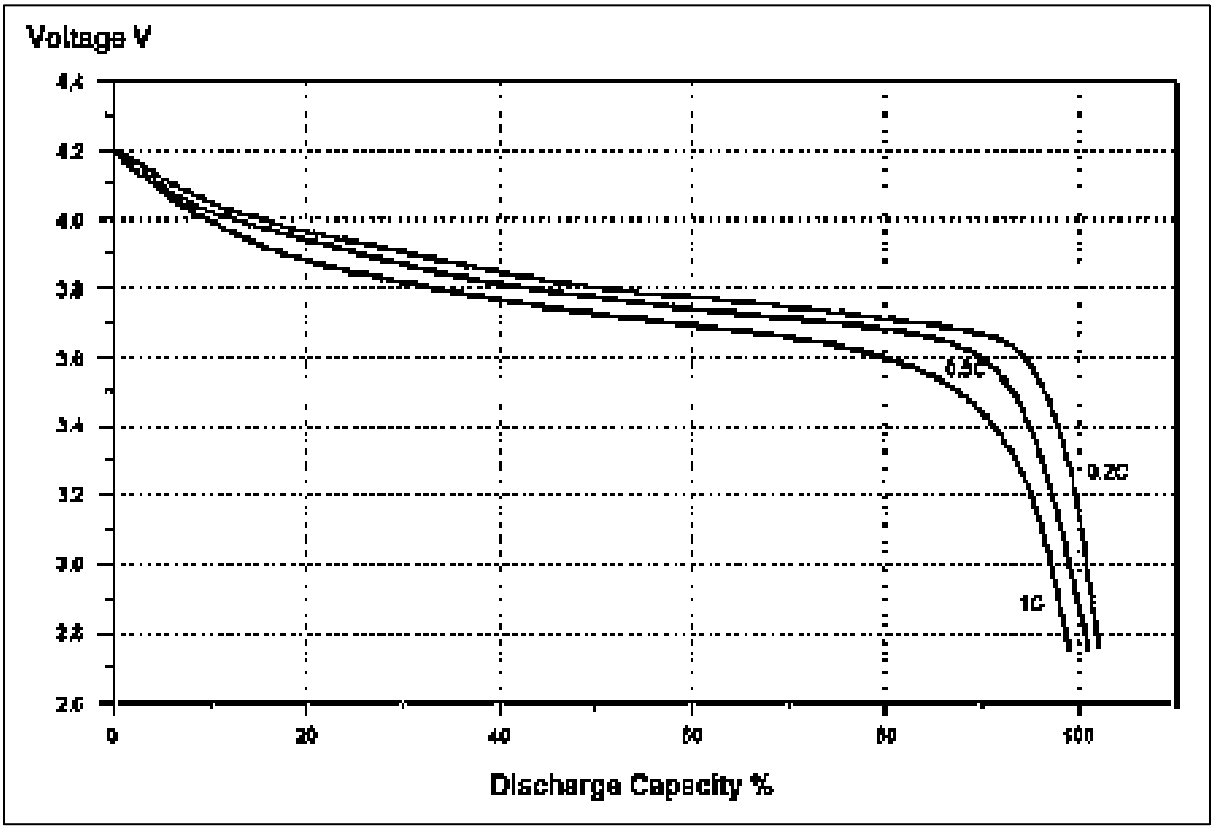

Figure 6 – Voltage vs. Discharge Capacity at Different C – Rates

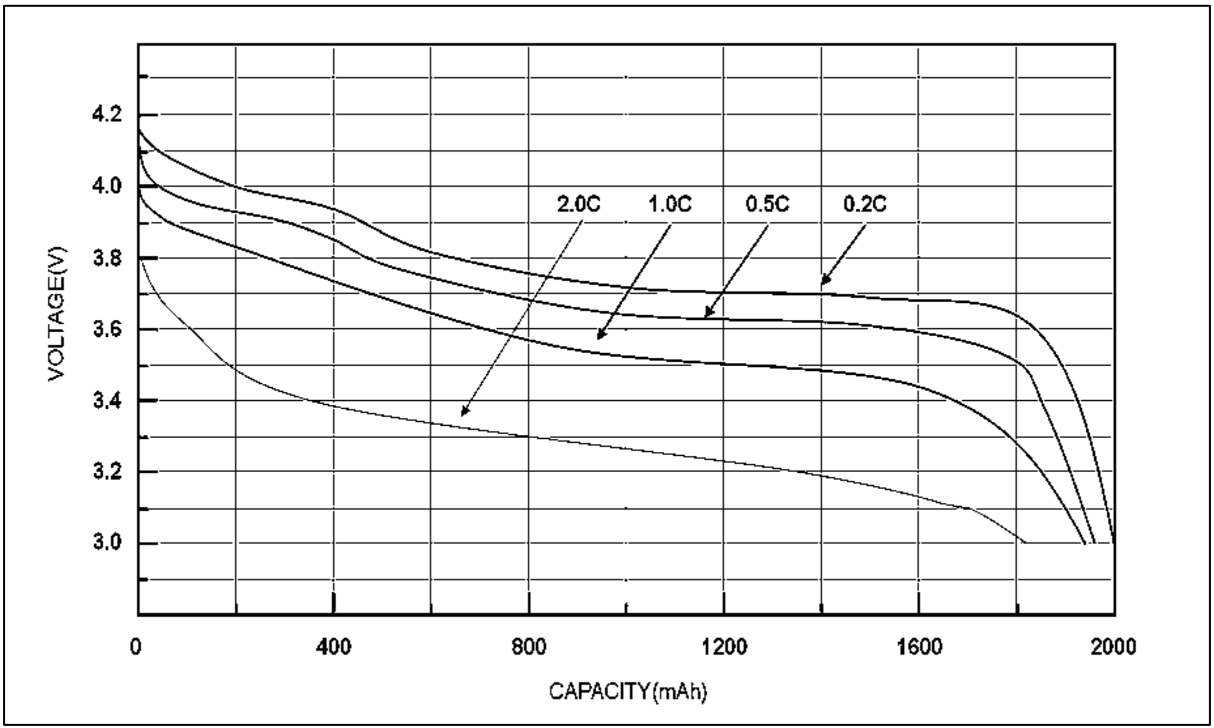

Figure 7 – Voltage vs. Drained Capacity During Discharging

VII. PERFORMANCE

The performance of these cells can be determined in terms of specific energy, volumetric energy density, charging/discharging efficiency, cycles of durability, self discharge rate etc. and a study compared among different commercially available cells and tabulated the resultant data. These are duly tabulated herein:

Parameters	Specifics
Specific Energy	100 to 250 Watt-hour/Kg
Volumetric Energy Density	900 to 2000 Joule/cm³
Charging/Discharging Efficiency	80 – 90%
Cycles of Durability	500 – 1000 cycles (variable for different materials)
Self Discharge Rate	2 – 3% per 30 days
Energy Capacity Per Unit Price	2-3 Watt-hour per dollar

Table 2 – Tabulation of Performance Parameters

	Lead Acid	Nickel Cadmium	Nickel Metal Hydride	Lithium Cobalt	Lithium Manganese	Lithium Iron Phosphate
Capacity	0.5	1.2	1.8	2.6->2.9AH	2.2-2.45AH	1.3-1.6AH
Voltage	2V	1.2V	1.2V	3.7V	3.7V	3.V
Energy Density(W/Kg)	35	45	70	167	110	100
Cycle Life	400	500	500	>500	>500	>1000
Life (Yrs) @ one charge/day	1	2	2	2	2	3
Charging Time	8 hrs	1.5 hrs	4 hrs	2-4 hrs	2-4 hrs	1-2 hrs
Self Discharge Rate (%/mo)	20%	30%	35%	10%	10%	8%
Safety	Good	Good	Good	Poor	Average	Good
High Temp Performance	Good	Good	Good	Average	Poor	Good
Cold Temp (0°F) Charge	Good	Fair	Fair	Fails	Fails	Fails
Cold Temp (0°F) Discharge	Good	Good	Poor	Poor	Good	Good

VIII. SAFETY OF OPERATION

Li-ion cells suffer thermal runaway when overheated. These are susceptible to damage when charged beyond its standard voltage range that is usually within 2.50 to 3.65V for most Li-ion cells. Short-circuiting a cell shall cause the cell to overheat and catch fire. Safety regulations such as IEC 62133 (Secondary cells and batteries containing alkaline or other non-acid electrolytes : Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications) and IEC 61960 (Secondary cells and batteries containing alkaline or other non-acid electrolytes : Secondary lithium cells and batteries for portable applications) are followed worldwide in manufacturing of these batteries.

Some safety features are : Shut-down separator (for overheating protection), Tear-away tab (for internal pressure relief) Vent (internal pressure relief in case of severe outgasing) and Thermal interrupt (protection from overcurrent /overcharging / accidental environmental exposure).

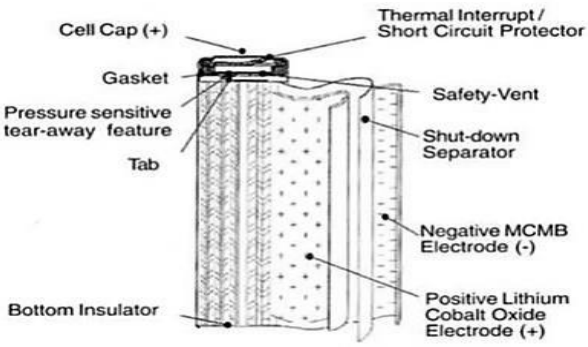

Figure 8 – Safety Features

IX. USES, ADVANTAGES & DISADVANTAGES

Advantages

- These have high energy density compared to other rechargeable batteries.
- These are often light weight.
- The specific energy content is high.
- No liquid electrolyte means they are immune from leaking.
- Fast charging and discharging rate.

Disadvantages

- These are rather expensive.
- There have been concerns with its safety of operation.

Uses:

These are used in electronic devices such as cell phones, laptops, digital cameras etc. These are also in power tools such as cordless drills, saws and various gardening equipments. In addition, these find use in transportation vehicles such as electric cars, bicycles, wheelchairs etc. Also, these are also used for aerospace applications.

X. CONCLUSION

Current research focuses on increment of battery life, energy density, safety, cost reduction etc. These batteries are already in widespread use in electronic devices, electrically powered vehicles, aerospace applications etc. Safety is still a concern for these batteries. Various researchers have come up with combinations of different materials for positive and negative electrodes. Lithium Iron Phosphate, Lithium Manganese Oxide, Lithium Manganese Oxide etc. are deployed as positive electrodes while Hard Carbon, Lithium Titanate, Tin/Cobalt Alloy etc. are being deployed as negative electrodes. Thus, it is to be seen how these battery technologies develop over time and is an active area of research for Chemists & Chemical Engineers.

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