## 5.0 Lithium Ion (Li-Ion)

## 5.1 Li-Ion Principles of Operation

The lithium Ion battery employs a metal oxide material (such as lithium cobalt oxide $LiCoO_2$), or a material with a tunneled structure (such as lithium manganese oxide $LiMn_2O_4$) as its positive electrode. The negative electrode is typically a graphitic carbon. During the charge and discharge processes, lithium ions are inserted or extracted from interstitial space between atomic layers within the active material of the battery.

## 5.2 Charge/Discharge Chemical Reaction

During charge, the positive material is oxidized and the negative material is reduced. In this process, lithium ions are de-intercalated from the positive material and intercalated into the negative material. (Intercalated – a reaction where lithium ions are reversibly removed or inserted into a host without a significant structural change to the host) The reverse process is present during a discharge cycle.

**Figure 5.2.1:** Charge/Discharge Chemical Reactions

Positive: $LiXXO_2 \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_{1-x}XXO_2 + Li^+ + xe^-$

Negative: $C + xLi^+ + xe^- \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_xC$

Overall: $LiXXO_2 + C \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_xC + Li_{1-x}XXO_2$

XX= Various Combining elements including Cobalt and Manganese

## 5.3 Overcharge/ Over Discharge

A strict charging regime is necessary to properly and safely charge lithium ion batteries. Most batteries contain a protective circuit to prevent overcharge and over discharge. This circuit limits the charge voltage to a maximum 4.3 volts, and also contains a thermal sensor, which disconnects charge if the temperature reaches 90 °C (194 °F). If a cell is inadvertently overcharged, the cell may heat up and vent with a flame. The Lithium Ion batteries permanently lose capacity when exposed to elevated temperature greater than 65 °C.

The protective circuit also limits the discharge voltage to between 2.7 and 3.0 volts per battery. In spite of these preventative measure, over discharge may still occur. If a lithium battery has dwindled to a voltage of less than 1.5 volts per battery, recharge should be avoided. Copper shunts may form inside the battery, causing a partial or total short circuit. In this case, the battery becomes unstable, charging the battery would cause excessive heat, and safety cannot be assured.

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## 5.4 Rate Capability

**Table 5.4.1:** Charge/Discharge Chemical Reactions

| **Typical Performance Characteristics of Lithium Ion Batteries** | |
|---|---|
| Operational Battery Voltage | 4.2 to 2.7 Volts |
| Specific Energy | 100 to 158 W/kg |
| Energy Density | 245 to 430 W/L |
| Continuous Rate Capability | Typical: 1C<br>High Rate: 5C |
| Pulse Rate Capability | Up to 25C |
| Cycle Life at 100% DOD | Typically 500 |
| Calendar Life | 3 - 5 years |
| Self Discharge Rate | 0.3% / month |
| Operable Temperature Range | -20 °C to 60 °C |
| Memory Effect | None |

**Note:** Characteristics can change according to improvements in chemistry or special niche requirements.

## 5.5 Discharge Characteristics

At a constant current discharge rate, the lithium ion battery maintains a relatively flat voltage discharge profile with a steep decrease in the profile near the end of discharge. The battery should not be discharge to less than 3.0 volts per battery.

## 5.6 Charging Characteristics

Operating temperatures for charging are –10 °C to 60. The lithium ion batteries require a controlled charge regime to properly charge the battery and prevent overcharge during the charge cycle. The two-stage charge cycle must be performed to fully charge the battery. This is called a CC/CV charge cycle.

- The first stage of the charge cycle is a constant current charge until the battery voltage reaches 4.1 to 4.2 volts.

- Upon reaching this peak voltage, a constant voltage charge is initiated until the charge current reduces to 3% of the rated current. Upon completing charge, a top off charge may be used to insure to counteract the self-discharge of the battery and protective circuit. This top off charge may be initiated when the open circuit voltage of the battery reaches less than 4.05 volts and terminate upon reaching the full charge voltage of 4.1 to 4.2 volts. Depending on the battery, this top off charge may be repeated once every 20 days.

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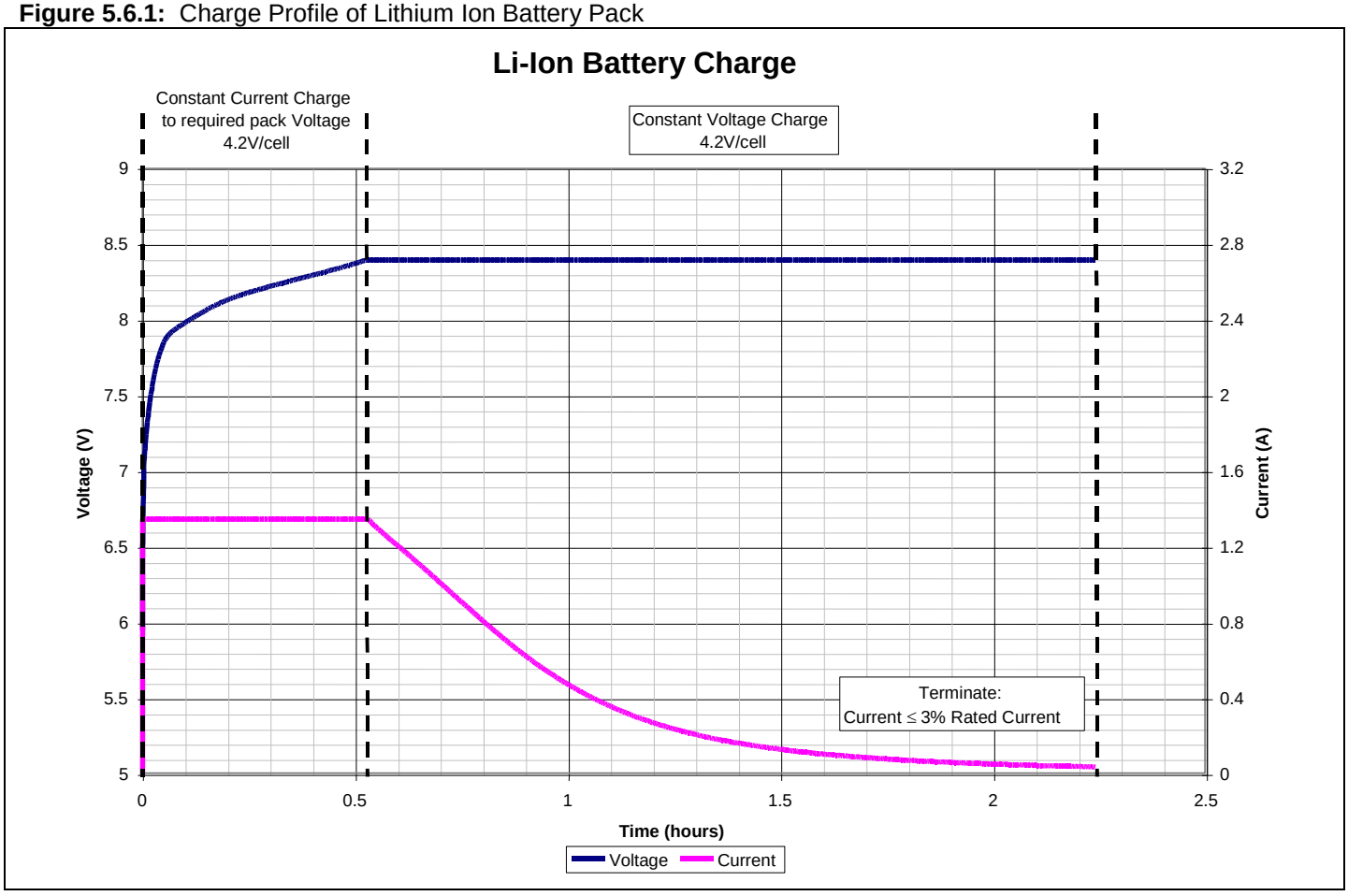
**Figure 5.6.1:** Charge Profile of Lithium Ion Battery Pack




## 5.7 Li-Ion Battery Storage Guidelines

Batteries should be stored at 15 °C (59 °F) with a 30% to 50% state of charge

## 5.8 Li-Ion Cell Nomenclature

### *5.8.1 Pack Nomenclature*

When Lithium ion cells are assembled into packs of series and parallel, the arrangement is specified in the form NSXP. Where N is the number of cells in series and X is the number of cells in parallel. For example a 3S4P pack of 1500 mAh cells would be built of four, three-cell series packs in parallel. The nominal voltage for this pack would be 11.1 V and the total capacity would be 6000 mAh.

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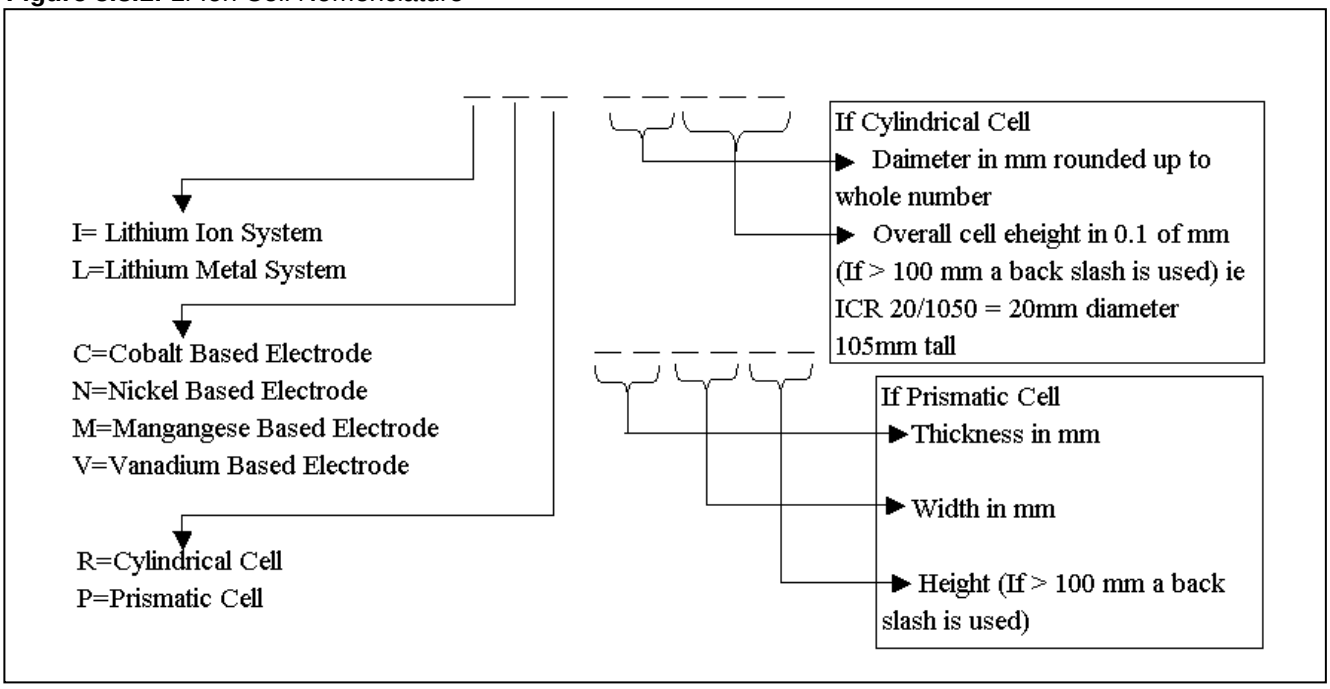
**Figure 5.8.1:** Li-Ion Cell Nomenclature




## 5.9 Li-Ion Cautions

Lithium Ion Batteries and packs that are abused may get hot, explode, or ignite and cause serious injury!

- Do not expose the battery to extreme heat
- Do not short circuit battery
- Do not puncture or modify the battery or pack
- Do not immerse the battery pack in water
- Do not install the battery/ pack backwards
- Charge only with charger specified by equipment manufacturer

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