The Lithium-Ion Battery

Service Life Parameters

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RECHARGE aisbl
Li-ion battery ageing mechanisms

The battery life duration is generally limited by the ageing of the Li-ion battery electrodes and chemistry.

It can be measured through the evolution of two performances criteria:

- The evolution of the battery capacity
- The evolution of the battery internal resistance

According usage conditions, other criteria may limit the performances of the battery such as the effect of temperature and the shelf life,....
Li-ion battery ageing mechanisms

- The progressive reduction of the battery capacity over life

- The progressive increase of the internal resistance of the battery: it limits the battery power due to voltage reduction.

The ageing is often attributed to 2 cumulative mechanisms

- Calendar life ageing: effect of time and temperature on performances.

- Cycle life ageing: effect of charge and discharge cycles on performances.
The battery chemistry is characterized by the cathode material (LCO, NMC, LFP, etc...)* and the anode material (Graphite, LTO, ..)**

*Cathode materials: LCO= Lithiated Cobalt Oxyde, NMC= Lithiated Nickel Manganese Cobalt Oxyde, LFP= Lithium Iron Phosphate.

**Anode material: LTO= Lithium Titanate.
Li-ion batteries key features

• Multiple Chemistries:

Li-Ion is a generic term for rechargeable batteries

It overs several types of battery chemistries and several formats for various applications (see next slides).

• Improving technology:

This technology is still in an development phase

New chemistries and designs are progressively introduced on the market.
## Choices in Li-ion Chemistry

The type of chemistry will impact performances and safety.

<table>
<thead>
<tr>
<th></th>
<th>LCO LiCoO₂</th>
<th>NCA LiNiCoAlO₂</th>
<th>NMC LiNiMnCoO₂</th>
<th>LMO LiMn₂O₄</th>
<th>LFP LiFePO₄</th>
<th>LTO* Li₄Ti₅O₁₂</th>
<th>Si-C*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell Voltage</strong></td>
<td>4.2V/3.8V</td>
<td>4.0V/3.6V</td>
<td>4.2V/3.7V</td>
<td>4.2V/3.9V</td>
<td>3.6V/3.3V</td>
<td>2.8V/2.4V</td>
<td>4.2V/3.9V</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>+++</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><strong>Calendar Life</strong></td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>-</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cycle Life</strong></td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>--</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>++</td>
</tr>
</tbody>
</table>

* LTO and Si-C are anodes, which can be combined with any cathode.

The selection of a chemistry for a given application is a trade off between various parameters.
1. The battery is also characterized by its format.

   1. Button cells

   2. Hard cases: cylindrical or prismatic (aluminium welded can)

   3. Soft case or « pouch »

Reference: IEEE 1725 Standard
The industrial battery is independent of the cell format.

Li-ion packs technologies

Typical Li-ion Batteries Voltage and Weight

- Laptop
- Bicycle
- HEV
- EV
- Battery Management System
Li-ion ageing: power vs temperature and SOC

The battery power is impacted by the storage temperature and by the state of charge during storage.

Ref: Saft Li-ion NCA/graphite, M. Broussely IMLB12
Li-ion ageing: capacity & energy vs temperature

Capacity and energy are impacted by the storage temperature

Ref: Saft Li-ion NCA/graphite, M. Broussely IMLB12
The cycle life duration is often measured with cycling at 100% depth of discharge: in this case -15% capacity after 1000 cycles.

But the large majority of applications do not use 100 % of the battery capacity at each cycle ( limited depth of discharge by the user or by the Battery Management System).

Ref: Saft Li-ion LCO/graphite, M. Broussely IMLB12
The depth of discharge has a large effect on the number of cycle: 1 million cycles can be achieved at low DOD. => the battery management system can protect the battery while limiting the DOD.

Ref: Saft Li-ion LCO/graphite, M. Broussely IMLB12
The battery life duration is determined by 3 key factors

- The battery design: type and quality of selected materials and components, design of the product.

- The application constraints: temperature of operation, type of usage (from high power permanent cycling to permanent charge for back-up).

- The Battery Management System regulation mode: the more efficient is the battery protection, the longer the service life.

Consequently, the service life expectation can be as short as 1 to 2 years, (e.g. in cordless power tool) or up to 20 years (e.g. in stationnary back-up applications)!